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Air/Superfund National Technical Guidance Study Series Development of Example Procedures for Evaluating the Air Impacts of Soil Excavation Associated with Superfund Remedial Actions

PEI Associates, Inc., Cincinnati, OH

Prepared for:

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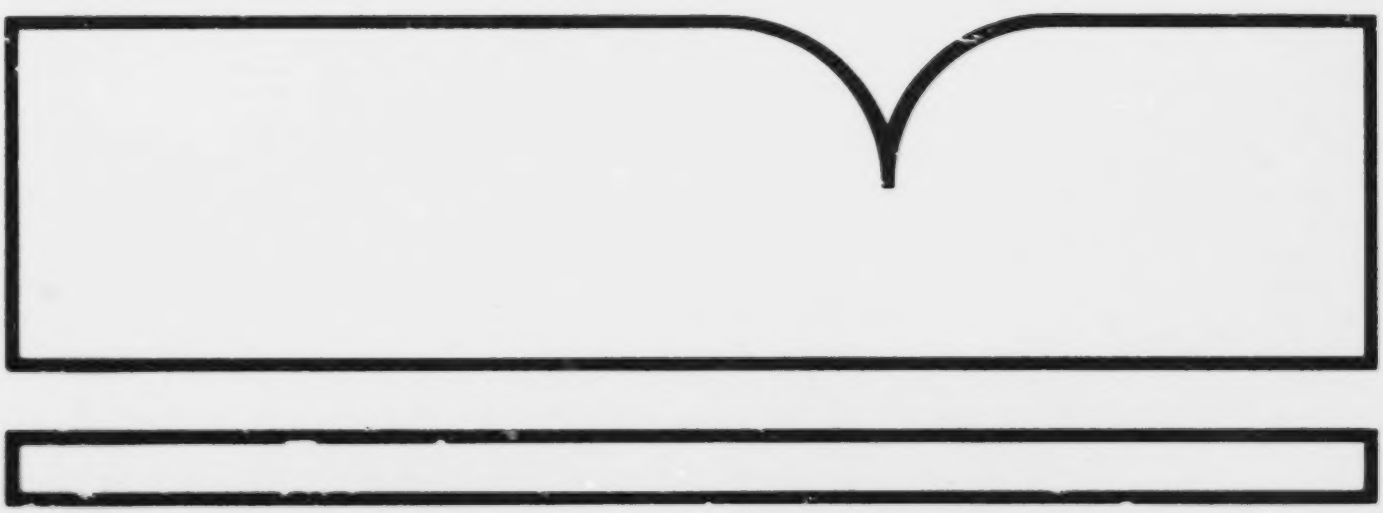

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The purpose of this project was to identify and define the computation requirements for estimating the air impacts from the remediation of Superfund sites. Two example sites employing soil excavation were selected because they represent a complex emission source. The estimation of air impacts from these sites include factors such as source type (point, area, or volume), location, and movement of the sources.

The procedures for the evaluation of the ambient impacts were divided into several subtasks. These included site characterization, selection of remedial alternatives, definition of remedial activities, estimation of emission rates for each remedial activity, determination of ambient concentrations from dispersion modeling, and evaluation of carcinogenic and noncarcinogenic risks based on dispersion modeling results.

The calculation of emission rates were used to estimate ambient impacts through dispersion models. The ambient concentration at various receptors of interest were compared to health based risk data and used to estimate an increased risk value at these receptors. Carcinogenic and noncarcinogenic effects were considered. The purpose of this effort, however, was not to produce a risk assessment at each site. Rather, it was to outline a set of procedures that could be used, with existing tools, to assist in the evaluation of air-pathway effects.

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DEVELOPMENT OF EXAMPLE PROCEDURES FOR EVALUATING THE AIR IMPACTS OF SOIL EXCAVATION ASSOCIATED WITH SUPERFUND REMEDIAL ACTIONS

by

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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July 1990

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SECTION 1

INTRODUCTION

Numerous remedial technologies can be used to clean up Superfund sites. Many of them are identified in the Cost Of Remedial Alternatives (CORA) model developed for the Superfund program. Obviously not all of the approximately 40 different remedial alternatives are applicable to every site. Also all remediation technologies do not have an air pathway impact. The ambient air impacts of each applicable remedial alternative for a Superfund site should be considered in the evaluation performed during the Feasibility Study (FS) phase. Estimating the effects from a remedial alternative requires the development and use of some relatively simplified computational techniques.

The purpose of this project was to identify and define the computation requirements for estimating the air impacts from the remediation of Superfund sites. Two example sites employing soil excavation were selected because they represent a complex emission source. The estimation of air impacts from these sites include factors such as source type (point, area, or volume), location, and movement of the sources. These factors are more complex for soil excavation when compared to air stripper or in situ soil vapor extraction. For example, one very important assumption in soil excavation is the degree of homogeneity in the soil contamination. It was assumed that large volumes contained homogeneous soil and contamination characteristics. In actual Superfund site applications, the site characteristics may be quite complex and necessitate a subdivision of the site into numerous smaller "homogeneous" volumes. Calculation procedures for the individual homogeneous volumes may then be performed much as they would be for a less complex site.

The procedures for the evaluation of the ambient impacts were divided into several subtasks. These included site characterization, selection of remedial alternatives, definition of remedial activities, estimation of emission rates for each remedial activity, determination of ambient concentrations from dispersion modeling, and evaluation of carcinogenic and noncarcinogenic risks based on dispersion modeling results. Existing

mathematical models were to be used to the extent possible, and key input data were to be identified. All assumptions necessary to complete the calculations were identified and documented.

The calculation of emission rates were used to estimate ambient impacts through dispersion models. The ambient concentration at various receptors of interest were compared to health based risk data and used to estimate an increased risk value at these receptors. Carcinogenic and noncarcinogenic effects were considered. The purpose of this effort, however, was not to produce a risk assessment at each site. Rather, it was to outline a set of procedures that could be used, with existing tools, to assist in the evaluation of air-pathway effects. Simplification procedures were to be identified for the calculations that might lend themselves to simpler calculations or perhaps graphical procedures. In addition, a computerization procedure was to be explored that might assist in the air pathway analysis.

SECTION 2

GENERAL APPROACH AND PROCEDURES

Although each Superfund site has unique characteristics, a general approach was defined that was applicable to a wide variety of sites and yet allowed the flexibility to accommodate a limited number of site-specific factors. These procedures are outlined below.

2.1 SITE CHARACTERIZATION

Both example sites were loosely based on actual Superfund sites in terms of size and volume of the contaminated area. In each case, the actual size and depth of contamination were used. The contaminants considered in these examples, however, differed from those actually present at the sites. For example, although these sites also include both semivolatile and nonvolatile contaminates for the purpose of this exercise, only volatile organic compounds (VOCs) contaminants present were considered for emission calculations. In actual applications, the nonvolatile and semivolatile compounds (particulates) may have to be considered.

Five VOCs were selected for emission rate calculations: benzene, 1-butanol, dichloromethane (methylene chloride), methyl ethyl ketone, and o-xylene. These compounds were selected because they represent a wide range of vapor pressures, solubilities, molecular weights, and Henry's Law constants for VOCs. These physical characteristics of VOCs are important to the emission rate calculation as they are the concentrations in the soil.

The concentrations of the various VOCs represented ranges of several hundred ppm up to 27,500 ppm, which might "typically" be encountered at Superfund sites. The contaminant levels also were assumed to be homogeneous within a specified contaminant zone. Site A represents a simple site with a single homogeneous contaminated zone. Site B represents two separate and different homogeneous zones. At an actual Superfund site, the contamination could be very heterogeneous. At an actual site, however, the contaminated zone can be subdivided into discrete homogeneous zones for the

purpose of calculation. Large and more complex sites could follow this subdivision process for calculation purposes.

Other factors, such as soil characteristics and the presence of a soil "cap" should be considered in the site characterization. These factors affect the volatilization rates for the various compounds, as the effective soil porosity controls the diffusion rates of the various compounds. These "other factors" or site characteristics were assumed for the example sites.

2.2 SELECTION OF REMEDIAL ALTERNATIVE

Excavation was selected as an option to be examined for each site for several reasons. First, emission rate models have been developed and have limited field validation data. Second, excavation is often considered at both remedial and removal sites. Finally, excavation activities represent a relatively complex series of activities that produce both area and volume sources for ambient dispersion modeling purposes. The procedures outlined in this report focus on the ambient impact associated with soil excavation. Similar procedures could be used for other remedial options.

Following the selection of the remedial alternatives, a set of remediation steps was outlined. The excavation alternative included excavating of the soil cap, dumping the soil into a truck, excavating the highly contaminated soil zone, dumping it into a truck, transporting the contaminated soil, dumping the contaminated soil, and providing temporary storage of the soil prior to its ultimate disposal. With the site characteristics defined and remedial alternatives selected, the next step was to estimate emissions from each operation for each chemical.

2.3 ESTIMATION OF EMISSION RATES

Emission rates of each of the five compounds were estimated for the remedial activities. The emission calculations for excavation were based on the use of the RTI Landtreatment equations modified to accommodate the various activities associated with excavation. The ratio of each chemical to the total VOC emissions was examined for each excavation activity, as well as its contribution to overall VOC emissions. These emission rates served as an input into the dispersion modeling analysis for determining ambient concentration estimates.

2.4 DISPERSION MODELING

The locations of remedial activities and their emission characteristics were input into the selected computer-based dispersion models to estimate both long-term and short-term ambient concentrations at numerous offsite receptor locations. Industrial Source Complex (ISC) models were selected initially to determine long-term (ISCLT) and short-term (ISCST) ambient concentrations. The meteorological conditions selected for the analysis were those from the Raleigh-Durham, North Carolina, airport.

The emission rates for the ISCST model were estimated for each hour of the day. Emissions from excavation and truck filling were combined to form one area "source." Emissions from hauling trucks were considered a line source, whereas the dumped contaminated soil was considered another area source. Air strippers, incinerators, and in situ soil vapor extraction units would be considered point sources, whereas lagoons or surface impoundments would be considered area sources. The principal advantage of the ISCST model is the large number and types of sources that can be evaluated simultaneously to estimate an overall ambient concentration over a variety of time periods (i.e., 1, 3, 8, and 24 hour averages). The highest 100 predicted ambient concentrations and their locations were listed for each averaging period. The disadvantage of the ISCST model is its long run-time requirements for execution.

The SCREEN model can be used to estimate 1-hour ambient contributions from individual sources. This model is limited to a single-source evaluation (point, area, or flare), can accept the input of atmospheric stability class and windspeed, and requires very short run times. Its principal disadvantages are that it cannot consider multiple sources, actual meteorological data, and averaging periods other than 1 hour. Because of these disadvantages the results must be manually converted to other averaging times and the contributions from multiple sources must be added.

Long-term concentrations were computed with the ISCLT model. Emission rates from each source were converted from their hourly values over the remediation period to an annual average. The ISCLT model permits simultaneous computation of contributions from multiple sources to the ambient concentration at specified receptors. Meteorology from the site may be used to compute annual averages. In the example site calculations for

long-term averages, meteorological data from the Raleigh-Durham, North Carolina, airport were used. The computational requirements for the execution of the ISCLT model required relatively short run times. Ambient concentrations for all models were computed in $\mu g/m^3$.

2.5 RISK ASSESSMENT

The dispersion model results for the site remediation activities can be used to compute risks associated with the alternatives selected. Both short-term and long-term ambient concentrations of VOCs were used in the evaluation of the risks. Short-term values are useful in evaluating acute effects, whereas the long-term values are most useful in evaluating chronic effects. Both carcinogenic and noncarcinogenic effects were considered.

Potency factors for carcinogens were available for two compounds--benzene and methylene chloride. Of the remaining compounds, only 1-butanol does not have health benchmark levels available. Both methyl ethyl ketone and o-xylene are listed in the Health Effects Assessment Summary Tables (HEAST) as noncarcinogenic toxicants. These values may be used to compute the values for risks associated with ambient concentrations and to establish ambient levels of concern for different levels of risk. Both procedures were used to determine if any unacceptable risks were associated with the selected remedial alternatives.

The carcinogenicity potency factors are extrapolated to 70-year exposures, whereas the remedial alternatives at the example sites represent relatively short-term exposures (2 to 6 months). Current Superfund guidance calls for prorating the actual duration of exposure to a 70-year exposure. A similar procedure that may be used is to prorate the 70-year exposure value down to the period of remediation. The results obtained are identical and it was this second procedure, that was used to compare the actual ambient concentrations with health related values. In these examples the 70-year values were prorated to 1 year and compared with annual ambient concentrations from the ISCLT model (which used emission rates prorated to an annual rate).

The noncarcinogenic hazard index is based on a long-term exposure. For the two noncarcinogens, the annualized emissions and corresponding ambient concentrations were compared with the hazard indices. Carcinogens may also

have noncarcinogenic effects, but no hazard index data were available for the two carcinogens.

Much less guidance is available on the evaluation of short-term exposures. Certainly, threshold limit values (TLVs) and permissible exposure levels (PELs) can be used as guidance and are often used for worker protection. The procedure for translating these values to the general public that may be exposed to high concentrations for short periods of time is not a well-defined, however. Work is currently underway within the Superfund program to provide guidance on evaluating short-term exposures.

Based on the risk and health effects estimates, the remedial alternative under consideration can be assessed and compared with other remedial alternatives for their risk values in addition to their costs.

SECTION 3

SITE DESCRIPTIONS AND REMEDIAL APPROACHES

This section presents descriptions of two sites that represent small to moderate-sized contaminated soil volumes for which excavation may be appropriate. Site A represents the least complex scenario and Site B represents a somewhat more complex arrangement. The proposed approach for large complex sites, however, would be similar to that used for smaller, less complex sites.

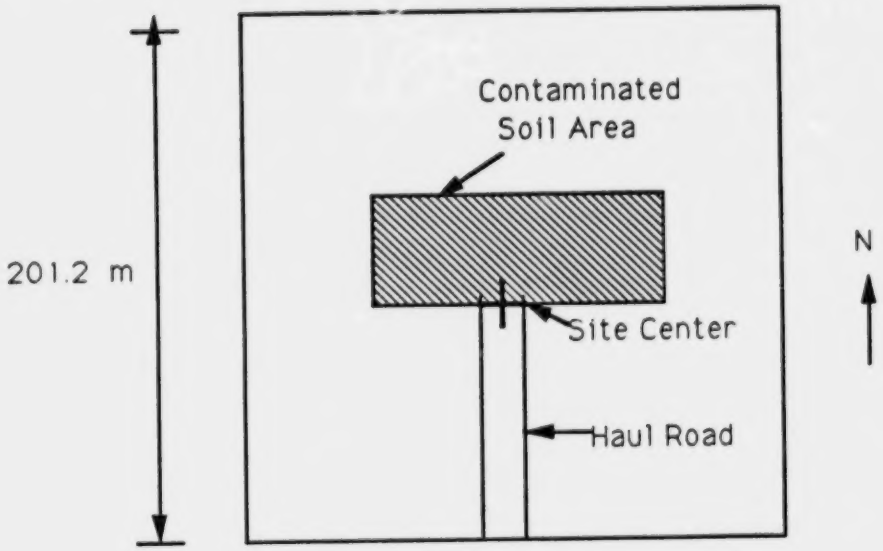
3.1 SITE A

Site A is a 10-acre site on which the contaminated soil zone is located near the center of the site. Soil in this area was contaminated by leakage from drums stored above ground. The contaminated zone is an area approximately 91 meters (300 ft) by 23 meters (75 ft), where the contamination extended to approximately 2 meters (6.8 ft) below the surface. This zone is considered homogeneous in soil type and contaminant concentration. Figure 1 presents the site configuration.

The initial remedial steps included removing all the stored drums and stopping the addition of more contamination to the site. A clay soil cap approximately 0.5 meter deep was placed on top of the contaminated soil to minimize rainwater penetration and infiltration through the soil.

As shown in Table 1, the contaminated soil contains five VOCs. The VOC found in the highest concentration is methylene chloride, which represents over 54 percent of the VOC contamination. The VOC found in the lowest concentration is 1-butanol.

The remedial alternative selected for Site A was soil excavation. A total of 3823 cubic meters (5000 yd^3) of material would be removed. The soil excavation would occur on an 8 hour/day, 6 day/week schedule. The average removal rate would be 885 cm^3/s (24-hour average) during the 2 month remediation period. The excavated soil would be transported by truck to an offsite Resource Conservation and Recovery Act (RCRA) site approximately 10 miles away, where it would be thermally desorbed of the VOCs. The "cleaned"



Contaminated Zone Dimensions: 91.4 m x 22.9 m
Haul Road Length: 100.6 m

Figure 1. Site A configuration.

TABLE 1. SOIL CONTAMINANT CONCENTRATIONS FOR SITE A

Compound	Soil concentration, mg/kg	Soil concentration, g/cm³	Fractional percentage of VOC in soil
Benzene	2,700	0.0049	0.0542
1-Butanol	1,440	0.0026	0.0284
Methylene chloride	27,500	0.0495	0.5417
Methyl ethyl ketone	6,880	0.0124	0.1355
o-xylene	12,000	0.0216	0.2403
Total	50,770		

soil would be returned to the site to fill in the excavated area and to restore the site to a "clean" condition.

The excavation procedure proposed for removing the soil is a vertical column removal procedure. In this procedure, a backhoe is used to dig up the soil and place it in a truck for transport. The soil cap is removed first to expose the contaminated soil below the cap. As the soil is dumped into the truck, VOC emissions are generated from the soil gases incorporated in the soil cap. The exposure of the contaminated soil layer and the subsequent exposure of each new area as a bucketful of material is removed from above also generates VOC emissions. The movement, dumping, and truck transport of the contaminated soil layer also generates emissions. Once remediation has begun, constant VOC emissions from the exposed contaminated soil zone contribute to both short- and long-term emissions. Figure 2 shows the procedures involved and the emission points.

Based on its characteristics, the soil was treated as being in two distinct zones. The soil cap was treated as a relatively clean, low-moisture, and moderately compacted soil. The contaminated soil was treated as a low-moisture compacted subsoil. These definitions and assumptions help to define diffusion rates for the various VOCs through the soil as the soil is excavated. The soil cap is assumed to contain a concentration of VOC that is 1 percent of the value for the contaminated soil layer. The contaminated soil layer is assumed to contain the initial concentrations specified in Table 1.

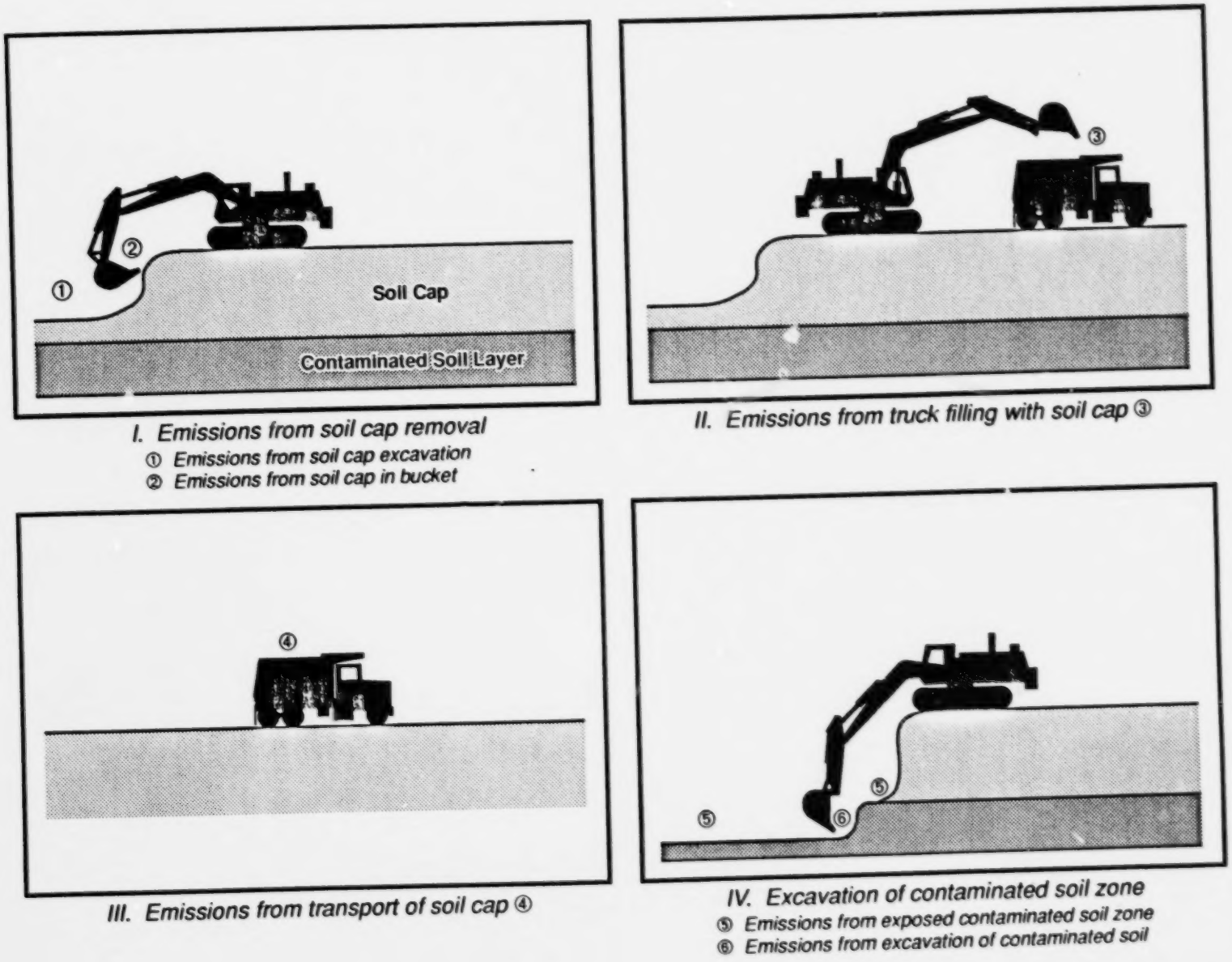

①
②
Soil Cap
Contaminated Soil Layer
I. Emissions from soil cap removal
① Emissions from soil cap excavation
② Emissions from soil cap in bucket
③
II. Emissions from truck filling with soil cap ③
④
III. Emissions from transport of soil cap ④
⑤
⑥
⑤
IV. Excavation of contaminated soil zone
⑤ Emissions from exposed contaminated soil zone
⑥ Emissions from excavation of contaminated soil

Figure 2. Summary of emission points from soil handling operations.

3.2 SITE B

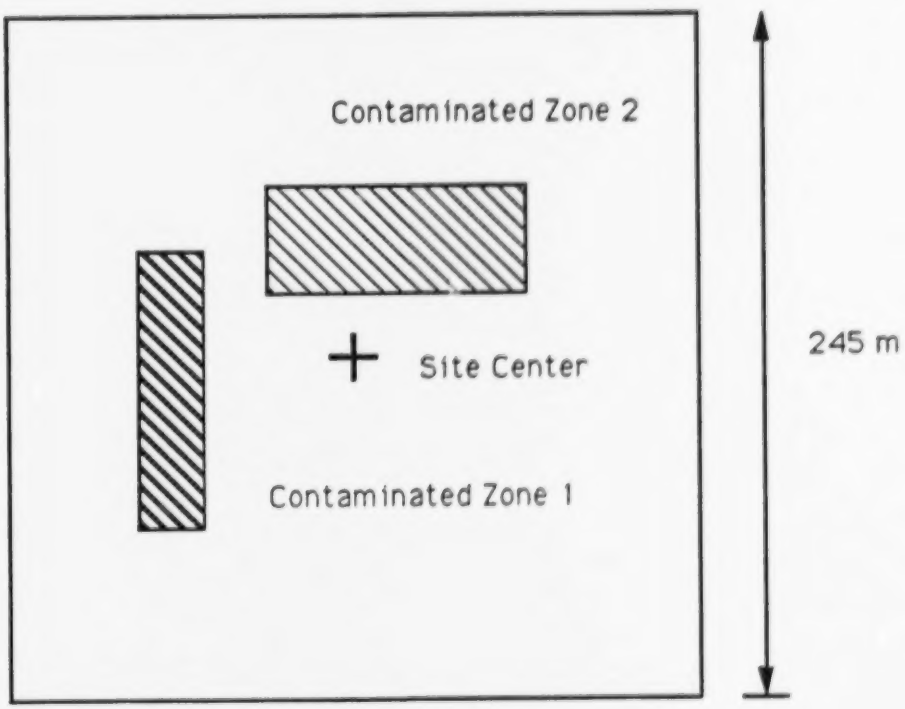
Site B is a 15-acre site (approximately 60,000 m^2) with two separate contaminated zones. Each zone has a distinct chemical composition, but each is considered homogeneous within itself. The site plot plan in Figure 3 indicates the approximate location of each contaminated zone.

Zone 1 of Site B encompasses an area of approximately 930 m^2 (10,000 ft^2) in which contamination reaches an average depth of 4.11 m (13.5 ft). The contaminated soil volume totals approximately 3823 m^3 (5,000 yd^3), and the contaminants are 1-butanol, methyl ethyl ketone, and benzene.

Zone 2, the larger of the two zones, encompasses an area and includes a volume of contaminated soil twice as large as those in Zone 1. The approximate area is 1860 m^2 (20,000 ft^2), and contamination reaches an average depth of 4.11 m (13.5 ft). The total contaminated soil volume is approximately 7646 m^3 (10,000 yd^3). This zone is contaminated with methyl ethyl ketone, methylene chloride, and o-xylene. The contaminant level within Zone 2 is considered homogeneous. Although both zones contain one identical compound (methyl ethyl ketone), each zone was considered separately because of the contamination level. Ground water has been contaminated by the VOCs in the soil and will require remediation. Table 2 presents the concentrations of the VOCs within each zone.

TABLE 2. SOIL CONTAMINANT CONCENTRATIONS AT SITE B

Location/compound	Soil concentration, mg/kg	Soil concentration, g/cm^3	Fractional percentage of VOC in zone
Zone 1			
Benzene	17[illegible]	0.0032	0.2760
1-Butanol	18[illegible]	0.0034	0.4649
Methyl ethyl ketone	3175	0.0057	0.2592
Zone 2			
Methylene chloride	8330	0.0150	0.4693
Methyl ethyl ketone	2930	0.0053	0.1651
o-Xylene	6440	0.0116	0.3628



Contaminated Area Dimensions
Zone 1: 91.4 m x 22.9 m
Zone 2: 91.4 m x 45.7 m

Figure 3. Site B configuration.

The remedial alternative investigated for this site includes excavation and onsite incineration of all 11,470 m^3 (15,000 ft^3) of contaminated soil. The two contaminated zones will be remediated sequentially, not simultaneously starting with Zone 1. The total time for soil remediation is estimated to be approximately 6 months--2 months for Zone 1 and 4 months for Zone 2. The soil excavation procedures for each zone would be similar; a vertical column method with a backhoe will be used for removal. The excavation schedule would call for excavation 8 hours/day, 6 days/week. The average soil removal rate would be 885 cm^3/s (24-hour average).

A relatively uncontaminated layer of soil is assumed to be on top of the contaminated zone. The concentration of the three VOCs are assumed to be in the same proportions, but at only 1 percent of the level of the concentrations in the contaminated zone. This soil cover depth extends to approximately 0.5 meter below the surface. The soil in the contaminated zone extends below this level.

The soil cover is to be removed by backhoe excavation, loaded into trucks, and hauled to the incinerator feed bin. The incinerator systems and buildings are designed to capture VOC emissions from the bin after the material is dumped and to feed to the primary and secondary air systems for destruction in the incinerator. Little onsite storage capability will be provided for unprocessed soil beyond what the feed bins can hold (24 hours of feed) so as to minimize VOC emissions and additional spreading of contaminated soil. The treated soil will be stored on site until it is ready to be used to refill the excavated soil area. The incinerator is designed to remove and destroy 99.99 percent of the benzene from the soil. Similar destruction removal efficiency is expected for the other VOCs. Only VOC emissions from the soil handling around the incineration were considered in the example calculations. Additional impacts would have to be considered for particulate and acid gases associated with incineration.

Emissions to be considered for Site B are those associated with excavation, transport, and dumping of contaminated soil and incinerator emissions. Emissions from the boiler stack of the high-temperature air stripper were not included in this example site analysis.

SECTION 4

EMISSION RATE CALCULATIONS

4.1 GENERAL APPROACH FOR EMISSION RATE CALCULATIONS

Numerous mathematical models are available for describing emission rates from an undisturbed Superfund site and from some remedial processes. Few models, however, have been designed with remedial activities in mind, especially when soil excavation is involved. Most mathematical models and procedures are adaptations of existing models for undisturbed soil. This also applies to the calculation of emissions resulting from excavation work at the two example sites.

One such approach was to modify the RTI Landtreatment Model to account for emissions generated by soil excavation. The RTI Landtreatment Model and the Thibodeaux-Hwang Models,[1] which are very similar, predict a time variant emission rate that is a function of the diffusion rate of the VOC through the air-filled pore spaces in the soil. The time-dependent equation was considered applicable to soil excavation. Radian conducted a survey of Superfund sites and proposed several sites that would typify soil excavation activities.[2] Typical equipment sizes, operating cycles, and removal rates were also defined so the equations would be as applicable to the excavation activities as possible. These values and modifications are discussed in Reference 2. The results of the equations produce an emission rate of an organic species per unit volume of soil exposed and handled.

Several basic equations are used in the calculation of emissions associated with excavation activities. For the most part, the equations for each excavation step follow a similar format, but they must be performed sequentially because each succeeding step accounts for VOC losses that have occurred in all previous steps. Detailed computations are not presented here, but the equation formats are presented for illustration purposes.

Once the general soil removal procedure has been outlined, the equations may be applied sequentially to estimate emissions from each soil removal step by inputting the appropriate values. (These equations are currently under

review and may be modified). The same values for removal rate, equipment cycle times, and equipment dependent characteristics were used in the emission rate estimates for each chemical at each step. Typical values for the remediation characteristics were also defined for each step.

Two values used consistently in each equation are K_{eq}, the partition coefficient between the quantity of a specific VOC in the gas phase and VOC in the liquid phase, and D_e, the effective diffusity of the compound through the soil pore spaces. These values were calculated first.

The value of K_{eq} can be calculated by

$$K_{eq} = \frac{H_i E_a}{RTE_w} \quad (1)$$

or

$$K_{eq} = \frac{P_i^* MW_{ORG} E_a}{RTL} \quad (2)$$

where
- H_i = Henry's Law constant of species i (atm.m^3/gmol)
- E_a = Air porosity of soil (vol/vol)
- R = 8.21 x 10^{-5} atm·m^3/gmol·K in Equation 1
- R = 82.1 atm·cm^3/gmol·K in Equation 2
- T = Temperature (K)
- E_w = Volume fraction occupied by the waste in the soil (vol/vol)
- P_i^* = Vapor pressure of species i (atm)
- MW_{ORG} = Average molecular weight of organic waste phase (g/mol)
- L = Organic waste loading (g organic/cm^3 soil)

Equation 1 is used when soil concentrations are low and the soil gas concentration is assumed to be in equilibrium with the soil moisture. For this exercise, the soil cap or surface soil was assumed to be characterized by this equation. Equation 2 is used for higher soil concentrations, and the soil gas concentration is governed by Raoult's Law. The subsurface contaminated soil was assumed to be characterized by Equation 2. It is possible that the contaminated soil layer may be governed by Equation 1 (Henry's Law) for some highly soluble VOC's, but no effort was made to determine if Equation 1 should be applied for these examples and it was assumed that soil concentrations were sufficiently high to use Raoult's Law.

For some compounds that are both highly volatile and very soluble, this could result in a significant difference in the estimated emission rate.

The effective diffusion rate is calculated by the following equation:

$$D_e = D_a \frac{E_a^{3.33}}{E_T^2} \quad (3)$$

where D_a = Diffusity in air (cm^2/s)

E_a = Air porosity of soil (vol/vol)

E_T = Total porosity of soil (vol/vol).

Several values (shown in Table 3) are recommended based on soil conditions.

TABLE 3. REPRESENTATIVE SOIL POROSITY

Soil type/ moisture content	Porosity, vol/vol	
	Total porosity (E_T)	Air-filled porosity (E_A)
Surface		
Low moisture	0.61	0.50
High moisture	0.61	0.35
Compacted subsoils		
Low moisture	0.35	0.30
High moisture	0.35	0.15

Whereas the values of K_{eq} and D_e could change as a result of the soil excavation activities, they are assumed to remain constant for the sake of simplicity.

4.1.1 Excavation of Soil Cap and Contaminated Waste Layer

The following equation is used to calculate the mass of material emitted from excavation of the soil cap and the contaminated waste layer:

$$M_i = 0.72 \left[\frac{K_{eq} D_e \pi^2 t}{4} \right]^{0.5} \frac{C_{oi}}{d_L} \quad (4)$$

where M_i = Emission rate of species i, (g/cm^3 soil handled)

K_{eq} = Partition coefficient of species i (previously defined)

D_e = Effective diffusity of species i (previously defined)

t = Cycle time of soil exposure (s)

C_{oi} = Initial concentration of species i (g/cm^3 soil) in the waste layer

d_L = Depth of layer removed (cm).

4.1.2 Exposure of Contaminated Waste Layer

Equation 5 is used to estimate VOC emissions from the exposed soil waste layer:

$$M_i = 0.72 \left[\frac{K_{eq} D_e \pi^2 t}{4d^2} \right]^{0.5} \quad (5)$$

where d = Depth of soil waste layer under the soil cap (cm).

K_{eq} = Partition coefficient of species i (previously defined)

D_e = Effective diffusity of species i (previously defined)

t = Time to remove the soil cap.

4.1.3 Emissions From Soil in the Excavation Bucket, Truck Filling, Truck Transport, and Truck Dumping

An equation of identical form can be used for each of these operations, but with different values for d, depth of each soil layer, and t, exposure or cycle time. The equation is as follows:

$$M_i = 0.72 \left[\frac{K_{eq} D_e \pi^2 t}{4d^2} \right]^{0.5} (C_{oi} - M_{TOTi}) \quad (6)$$

where $M_{TOT_i} = \Sigma M_i$ of all previous steps prior to current remediation step.

The equation takes into account the losses from the previous steps. This equation is evaluated separately for both the soil cap and the contaminated waste layer.

4.1.4 Total Emissions for Excavation

The results of the preceding equations permit the estimation of the VOC emissions for each operation and for each species. The results of each equation are expressed in grams of emissions per cubic centimeter of soil. Total emissions of VOCs from each step or each species may be obtained by summing the results of the calculations. Hourly, daily, monthly, and annual emission rates can be estimated by using soil removal rates (cm^3/s). A summary of these results was computed for each site. Values for exposure time, depth of exposed layers from various operations, were obtained directly from values reported by Radian.[2]

4.2 EMISSION RATE RESULTS FOR SITE A

The characterization data and the "typical" values for removal of the soil layers was input into the equations to estimate the emission rates for the site. The steps for which emissions were calculated were excavation of the soil cap, emissions from the soil cap in the excavation bucket, emissions from the soil cap material as the truck is filled, emissions from the transport of the soil cap offsite, emissions from exposure of the contaminated waste layer, excavation of the contaminated waste layer, emissions from the contaminated soil in the excavation bucket, emissions from contaminated waste layer during truck filling, and emissions from transport of the contaminated waste layer. Once the material was offsite, emissions were no longer considered. Emissions for all five contaminants were calculated. Table 4 lists the pertinent physical constants for the five compounds. The overall 24-hour average soil removal rate was 885 cm^3/s. This value was divided according to the volume proportion of the soil cap and contaminated zone to calculate the emission rate for each component (g/s). The soil cap removal rate was 292 cm^3/s and the contaminated soil zone removal rate was 593 cm^3/s (24-hour average).

TABLE 4. PROPERTIES OF CHEMICALS USED IN SITE A EXAMPLE PROBLEMS

Compound	Molecular weight, g/gmol	Vapor[a] pressure, mmHg	Henry's Law[b] constant, atm·m³/gmol	Diffusivity in air, cm²/s
Benzene	78	101	5.50×10^{-3}	0.0932
1-Butanol	74	6.5	8.01×10^{-6}	0.081
Methylene chloride	85	427.8	3.19×10^{-3}	0.100
Methyl ethyl ketone	72	77.5	2.72×10^{-5}	0.095
o-Xylene	106	2.77	5.27×10^{-3}	0.0628

[a]Properties at 25°C.

[b]Estimated from vapor pressure/solubility characteristics at 25°C.

4.2.1 Emissions From Removal of Soil Cap

The soil cap is assumed to be equivalent to a low moisture surface soil with a total porosity value of 0.61 and an air-filled porosity of 0.50. Soil concentrations were assumed to be 1 percent of the value for each contaminant in the contaminated waste layer, and Henry's Law was assumed to apply. Table 5 presents the results. The emission rate value in g/s represents a 24-hour average.

TABLE 5. EMISSIONS FROM SOIL CAP REMOVAL--SITE A

Compound	Emission rate, g/cm³	Emission rate, g/s	Fractional VOC percentage
Benzene	2.22×10^{-6}	6.46×10^{-4}	0.1700
1-Butanol	5.48×10^{-8}	1.60×10^{-5}	0.0042
Methylene chloride	6.79×10^{-6}	1.98×10^{-3}	0.5216
Methyl ethyl ketone	2.94×10^{-7}	8.59×10^{-5}	0.0226
o-Xylene	3.75×10^{-6}	1.09×10^{-3}	0.2878
Total VOC	1.30×10^{-5}	3.82×10^{-3}	

4.2.2 Emissions From Soil Cap in Excavation Bucket

Soil characteristics and K_{eq} were assumed to be constant. Equation 6 was used with a value of t=30 seconds for soil exposure, d=150 cm for depth of exposed material in the bucket and the losses of material accounted for from the excavation action. Table 6 presents the results.

TABLE 6. EMISSIONS FROM SOIL CAP IN BUCKET--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	1.26×10^{-6}	3.67×10^{-4}	0.1842
1-Butanol	3.28×10^{-8}	9.58×10^{-6}	0.0048
Methylene chloride	4.00×10^{-6}	1.17×10^{-3}	0.5867
Methyl ethyl ketone	1.42×10^{-7}	4.15×10^{-5}	0.0208
o-Xylene	1.39×10^{-6}	4.06×10^{-4}	0.2034
Total VOC	6.83×10^{-6}	1.99×10^{-3}	

4.2.3 Emissions From Dumping Soil Cap Into Trucks

Equation 6 was used to account for previous losses and to estimate emission rates for each of the five compounds. The values used for exposure time and depth were 60 seconds and 51 cm, respectively. Table 7 presents the results.

TABLE 7. EMISSIONS FROM TRUCK FILLING (SOIL CAP)--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	5.07×10^{-6}	1.48×10^{-3}	0.1810
1-Butanol	1.36×10^{-7}	3.98×10^{-5}	0.0049
Methylene chloride	1.65×10^{-5}	4.82×10^{-3}	0.5893
Methyl ethyl ketone	5.91×10^{-7}	1.73×10^{-4}	0.0211
o-Xylene	5.71×10^{-6}	1.07×10^{-3}	0.2038
Total VOC	2.80×10^{-5}	7.34×10^{-3}	

4.2.4 Emissions From Transport of Soil Cap

Equation 6 was used to estimate emission rates from offsite transport of the soil. The values used for exposure time and soil depth in the truck were 720 seconds and 151 cm, respectively. Table 8 presents the results.

TABLE 8. EMISSIONS FROM TRANSPORT OF SOIL CAP--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	5.15×10^{-6}	1.50×10^{-3}	0.1668
1-Butanol	1.58×10^{-7}	4.62×10^{-5}	0.0051
Methylene chloride	1.85×10^{-5}	5.41×10^{-3}	0.6002
Methyl ethyl ketone	6.87×10^{-7}	2.01×10^{-4}	0.0223
o-Xylene	6.34×10^{-6}	1.85×10^{-3}	0.2055
Total VOC	3.08×10^{-5}	9.01×10^{-3}	

4.2.5 Emissions From Exposure of Contaminated Waste Layer

Equation 6 was used to estimate the emissions from exposure of the contaminated waste layer. The value for exposure time (t) was 300 seconds and the soil depth was 122 cm. The values for K_{eq} were calculated by using the Raoult's Law relationship. The results are presented in Table 9. The emission rate (g/s) is based on the 24-hour average removal rate of the contaminated soil layer.

4.2.6 Emissions From Excavation of Contaminated Soil Layer

Equation 4 was used to estimate the emissions from the excavation of the contaminated waste layer. This equation was modified slight by replacing the term for concentration with $(C_{oi} - M_{TOTi})$ to accommodate losses due to exposure of the contaminated soil layer prior to actual excavation (Subsection 4.1.5). A value of 60 seconds was used for the exposure and a value of 90 cm for d_L (soil depth). Table 10 summarizes the results.

TABLE 9. EMISSIONS FROM THE EXPOSURE OF THE CONTAMINATED WASTE LAYER--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	3.36×10^{-6}	1.99×10^{-3}	0.0393
1-Butanol	4.22×10^{-7}	2.50×10^{-4}	0.0049
Methylene chloride	7.21×10^{-5}	4.27×10^{-2}	0.8441
Methyl ethyl ketone	7.49×10^{-6}	4.43×10^{-3}	0.0877
o-Xylene	2.05×10^{-6}	1.21×10^{-3}	0.0240
Total VOC	8.54×10^{-5}	5.06×10^{-2}	

TABLE 10. EMISSIONS FROM EXCAVATION OF CONTAMINATED SOIL LAYER--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	2.04×10^{-6}	1.21×10^{-3}	0.0394
1-Butanol	2.56×10^{-7}	1.51×10^{-4}	0.0049
Methylene chloride	4.36×10^{-5}	2.58×10^{-2}	0.8439
Methyl ethyl ketone	4.54×10^{-6}	2.69×10^{-3}	0.0878
o-Xylene	1.24×10^{-6}	7.36×10^{-4}	0.0240
Total VOC	5.17×10^{-5}	3.06×10^{-2}	

4.2.7 Emissions From Contaminated Soil Layer in Excavation Bucket

Equation 6 was used to estimate emissions generated while the contaminated waste soil layer was in the bucket. A value of 30 seconds was selected for the exposure time and 150 cm for soil depth. Table 11 presents the results.

TABLE 11. EMISSIONS FROM EXCAVATION BUCKET--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	8.26×10^{-7}	4.89×10^{-4}	0.0413
1-Butanol	1.07×10^{-7}	6.36×10^{-5}	0.0054
Methylene chloride	1.68×10^{-5}	9.87×10^{-3}	0.8344
Methyl ethyl ketone	1.85×10^{-6}	1.10×10^{-3}	0.0926
o-Xylene	5.24×10^{-7}	3.10×10^{-4}	0.0262
Total VOC	2.00×10^{-5}	1.18×10^{-2}	

4.2.8 Emissions From Truck Filling With Contaminated Soil Layer

Equation 6 was used to estimate emissions generated from the filling the trucks with soil from the contaminated waste layer. The time value of 60 seconds and a depth of 51 cm were selected. Table 12 presents the results.

TABLE 12. EMISSIONS FROM TRUCK FILLING WITH CONTAMINATED SOIL LAYER--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	3.44×10^{-6}	2.03×10^{-3}	0.0411
1-Butanol	4.46×10^{-7}	2.64×10^{-4}	0.0053
Methylene chloride	6.97×10^{-5}	4.13×10^{-2}	0.8352
Methyl ethyl ketone	7.69×10^{-6}	4.56×10^{-3}	0.0922
o-Xylene	2.18×10^{-6}	1.29×10^{-3}	0.0261
Total VOC	8.35×10^{-5}	4.94×10^{-2}	

4.2.9 Emissions From Transport of Soil From the Contaminated Waste Layer

The final step for emissions generation at this site involves the transport of the contaminated waste layer soil from the site. Equation 6 was used to estimate the emissions from truck transport of the contaminated soil. The exposure time was 720 s with a depth of 151 cm. Table 13 presents the results.

TABLE 13. EMISSIONS FROM TRANSPORT OF SOIL FROM THE CONTAMINATED WASTE LAYER--SITE A

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Benzene	1.19×10^{-5}	7.04×10^{-3}	0.0412
1-Butanol	1.55×10^{-6}	9.15×10^{-4}	0.0054
Methylene chloride	2.41×10^{-4}	1.43×10^{-1}	0.8351
Methyl ethyl ketone	2.66×10^{-5}	1.58×10^{-2}	0.0922
o-Xylene	7.55×10^{-6}	4.47×10^{-3}	0.0261
Total VOC	2.89×10^{-4}	1.71×10^{-1}	

4.2.10 Summary of Emission Estimates for Site A

A review of the preceding tables indicates that the fractional percentage of the total VOC emissions for each species from each step is relatively constant within a soil layer although not precisely identical for each step. The emission rate for each chemical species is largely a function of the initial concentration, the method of partition coefficient calculation (Henry's or Raoult's Law), and the physical characteristics of the compound. The percentage of each compound lost compared with its initial concentration also depends on these factors, the excavation practices, and the soil characteristics.

The predicted VOC emission rates during the excavation process steps are generally higher for the contaminated waste soil layer than for the soil cap. This is not surprising given the lower concentrations assumed for the soil cap and the use of Henry's Law constants to calculate emission rates. The

predicted VOC emission rates are generally influenced by the larger volumes of soil and higher concentrations found in the contaminated subsoil zone. Table 14 presents the average fractional percentage of the individual VOCs for the soil cap, the contaminated zone, and the overall average value.

TABLE 14. SPECIES CONTRIBUTIONS TO OVERALL VOC EMISSIONS--SITE A

Compound	Fraction percentage for Soil Cap	Fraction percent age for contaminated zone	Fraction percentage for overall excavation
Benzene	0.1737	0.0407	0.0495
1-Butanol	0.0049	0.0052	0.0052
Methylene chloride	0.5815	0.8374	0.8191
Methyl ethyl ketone	0.0218	0.0911	0.0857
o-Xylene	0.2181	0.0256	0.0404

The overall excavation value is a weighted average percentage based on emission rates from both the soil cap excavation and the contaminated subsurface layer. On any given day, the remediation would be working to remove both layers. The overall fractional percentage was the value used to interpret ambient concentration data.

As shown in Table 14, the VOC with the highest emission rate is methylene chloride, based on its fractional contribution. This is as expected because its concentration is substantially greater than that of the other compounds. In addition, methylene chloride has a high vapor pressure and moderate Henry's Law constant. When input into the equations, these factors all act to generate a higher predicted emission rate. Also a substantial variation exists for several compounds, depending on which form of the partition equation is used to calculate the emission rate.

As shown in Table 15 the relative contribution from each remedial activity was examined. Again the relative contribution of each activity is influenced by the methodology used to calculate the partition coefficient and the assumptions used to compute the emission rates for each compound. For

TABLE 15. REMEDIAL ACTIVITY CONTRIBUTION TO VOC EMISSIONS FRACTIONAL CONTRIBUTION OF ACTIVITY--SITE A

Remedial activity	Soil cap	Contaminated zone	Combined
Excavation	0.1652	0.0977	0.1154
Bucket	0.0867	0.0377	0.0449
Truck filling	0.3554	0.1577	0.0670
Transport	0.3917	0.5455	0.6031
Exposure of contaminated zone		0.1614	0.1695

this site, however, the most substantial source of VOC emissions was determined to be the transport of soil off the site, followed in order by exposure of the contaminated waste layer (removal of the soil cap) and the actual excavation of the soil. Emissions from the soil while it is in the bucket and during the actual filling of the truck account for the smallest contributions based on the emission rate equations. These predictions assume no controls (tarps or foam) are used to control VOC emissions from any of the remedial process steps.

Equation 7 can be used to estimate emission rates and to establish an emission profile for the period of remediation. Assuming that the site was previously undisturbed except for soil sampling and removal of the leaking drums, a baseline VOC emission rate was estimated by using the RTI equation for instantaneous, time-dependent emissions.

$$E_i = \frac{M_o}{d} \left[\frac{1}{\frac{E_a}{K_g K_{eq}} + \left(\frac{\pi t}{K_{eq} D_e} \right)^{1/2}} \right] \quad (7)$$

where E_i = Flux rate of component i, g/cm^2 per second
M_o = Initial mass of i, g/cm^3 soil
d = Depth of contaminated layer, cm
E_a = Soil air porosity, dimensionless
K_g = Gas-phase mass transfer coefficient, cm/s
K_{eq} = Partition coefficient, g vapor/g liquid
t = Time, seconds
D_e = Effective diffusion rate of i, cm^2/s.

These variables are further defined in Reference 2. Assuming a 9-month period between sampling and remediation, the average VOC emission rate prior to remediation was 1.125×10^{-2} g/s, or 972 g VOC/day. The baseline emissions were calculated for the five individual compounds. Table 16 presents the relative contribution of each. During remediation, the estimated VOC emission rate increased to 2.988×10^{-1} g/s, or 25,816 g VOC/day. This represents an increase of 26.6 times the estimated baseline emission rate. Table 16 presents the relative contribution for the remedial alternative from Table 14 for comparison purposes. Although the process of remediation does increase total VOC emissions, it also changes the emission characteristics and contributions of the VOC species. Figure 4 is the short-term emissions profile for the site. This emissions profile is plotted on a semilogarithmic scale because of the larger increase in the VOC emission rate. The slight decrease in daily emissions is due to a decrease in emissions from the baseline area, as the unremediated area gradually decreases in size. At the end of remediation, emissions fall to zero for the site.

TABLE 16. FRACTIONAL CONTRIBUTIONS OF VOCS TO OVERALL EMISSION RATES--SITE A

	Fractional percentage	
Compound	Baseline	Remediation
Benzene	0.1014	0.0495
1-Butanol	0.0168	0.0052
Methylene chloride	0.7086	0.8191
Methyl ethyl ketone	0.1362	0.0857
o-Xylene	0.0366	0.0404

The VOC emission rates and the site characteristics form the basis for dispersion modeling at the site. These are discussed in Section 5.

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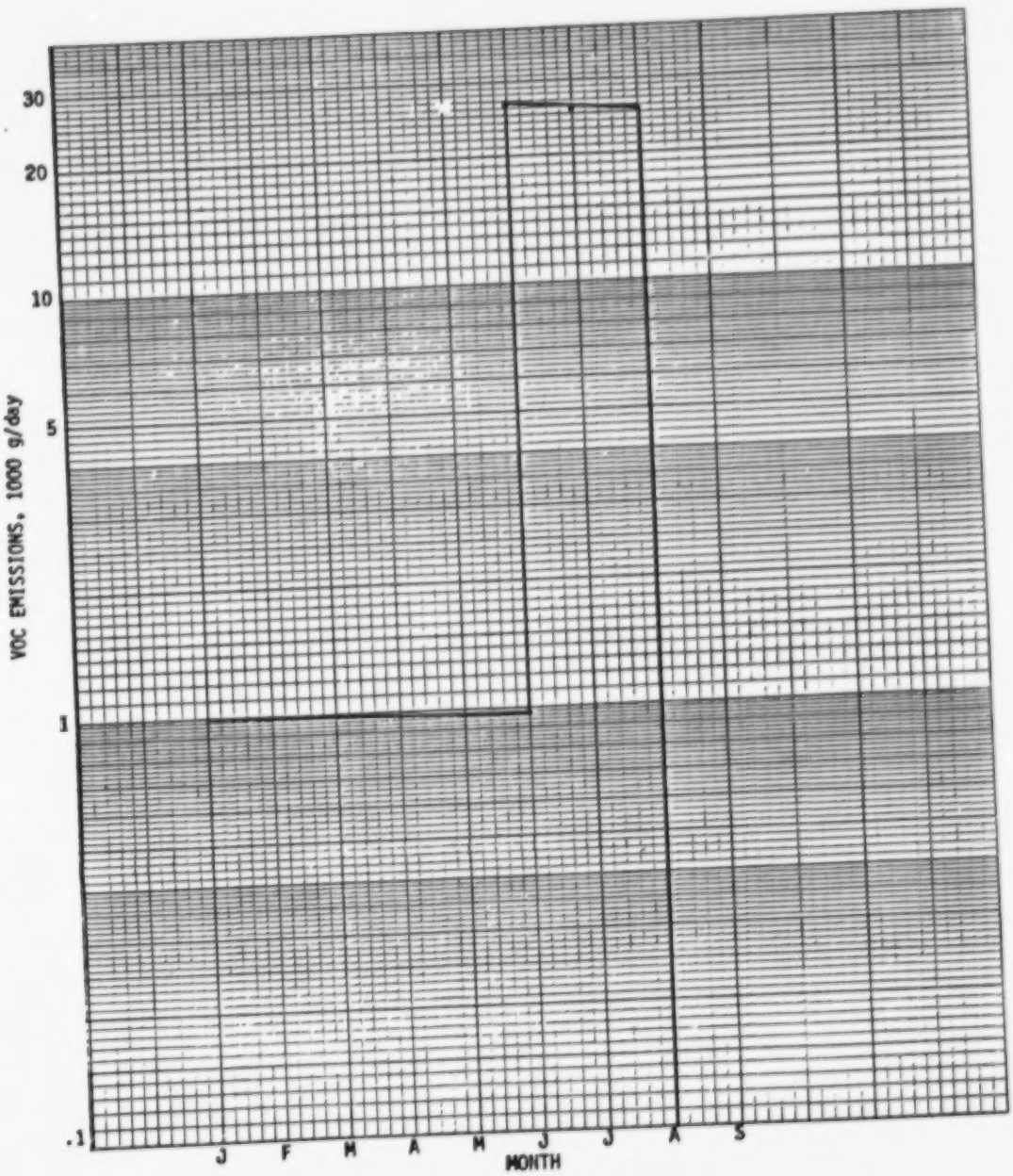

Figure 4. Daily emission profile for Site A.

4.3 EMISSION RATE RESULTS FOR SITE B

Site B is similar to Site A with regard to excavation. Some notable differences, however, include a much larger volume of soil to be remediated, onsite incineration of the contaminated soil, and lower concentrations of VOCs than on Site A. Also, the contaminated soil was divided into two distinct homogeneous zones of differing chemical composition. The excavation procedures are assumed to be similar to those for Site A including the use of the same equations and the addition of VOC emissions from truck dumping into the incinerator feed system. The two homogeneous zones, however, will be treated in sequence rather than simultaneously. The average rate of remediation for the site is 885 cm^3/s (based on a 24-hour average and on the same work schedule as for Site A). The relative removal rates, however, for the soil cap and contaminated soil zone differ because their relative volume percentages are different. The average rates for soil cap and contaminated soil removal are 131 and 754 cm^3/s, respectively, based on a 24-hour averaging period. These factors are used to convert the values for g/cm^3 soil handled to g/s values. The emission rates for each zone are presented separately in each table for the appropriate remedial step. The initial concentrations of contaminants have been presented previously in Table 2.

4.3.1 Emissions From Removal of Soil Cap

The surface soil was assumed to be equivalent to a low-moisture compacted soil with a total porosity value of 0.30 and an air filled porosity of 0.35. Surface soil concentrations were assumed to be 1 percent of the contaminated subsurface soil values in the same relative contributions as the contaminated zone. Henry's Law was assumed to apply in the computation of emission rates. The results are presented in Table 17.

4.3.2 Emissions From Soil Cap in Excavation Bucket

Equation 6 was used with a value of 30 seconds for the exposure time and 150 cm for the depth. Table 18 presents the results for the two zones.

4.3.3 Emissions From Truck Filling With Soil Cap

The emission rate for truck filling was estimated by Equation 6, with the exposure time, t, equals 60 seconds, and the depth equals 51 cm. Table 19 presents the results.

TABLE 17. EMISSIONS FROM SOIL CAP REMOVAL--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	1.32×10^{-6}	1.73×10^{-4}	0.8880
1-Butanol	4.67×10^{-8}	6.13×10^{-6}	0.0314
Methyl ethyl ketone	1.20×10^{-7}	1.57×10^{-5}	0.0805
Total (Zone 1)	1.49×10^{-6}	1.95×10^{-4}	
Zone 2			
Methylene chloride	2.16×10^{-6}	2.83×10^{-4}	0.5655
Methyl ethyl ketone	8.99×10^{-8}	1.18×10^{-5}	0.0236
o-Xylene	1.57×10^{-6}	2.06×10^{-4}	0.4110
Total (Zone 2)	3.81×10^{-6}	5.00×10^{-4}	

TABLE 18. EMISSIONS FROM EXCAVATION BUCKET (SOIL CAP)--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	7.54×10^{-7}	9.88×10^{-5}	0.8832
1-Butanol	2.80×10^{-8}	3.67×10^{-6}	0.0328
Methyl ethyl ketone	7.17×10^{-8}	9.40×10^{-5}	0.0840
Total (Zone 1)	8.53×10^{-7}	1.12×10^{-4}	
Zone 2			
Methylene chloride	1.27×10^{-6}	1.67×10^{-4}	0.5650
Methyl ethyl ketone	5.38×10^{-8}	7.06×10^{-6}	0.0239
o-Xylene	9.26×10^{-7}	1.21×10^{-4}	0.4111
Total (Zone 2)	2.25×10^{-6}	2.95×10^{-4}	

TABLE 19. EMISSIONS FROM TRUCK FILLING (SOIL CAP)--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	3.04×10^{-6}	3.99×10^{-4}	0.8802
1-Butanol	1.16×10^{-7}	1.53×10^{-5}	0.0337
Methyl ethyl ketone	2.98×10^{-7}	3.90×10^{-5}	0.0861
Total (Zone 1)	3.46×10^{-6}	4.53×10^{-4}	
Zone 2			
Methylene chloride	5.24×10^{-6}	6.87×10^{-4}	0.5648
Methyl ethyl ketone	2.24×10^{-7}	2.93×10^{-5}	0.0241
o-Xylene	3.81×10^{-6}	5.00×10^{-4}	0.4111
Total (Zone 2)	9.28×10^{-6}	1.22×10^{-3}	

4.3.4 Emissions From Transporting Soil Cap Material

Unlike Site A, the soil excavated at this site is transported to a thermal desorption/incinerator for soil treatment and dumped into the incinerator feed system. Time constants and depth of material assumptions, however, were the same as Site A (t = 720 seconds, d = 51 cm). Table 20 presents the results.

4.3.5 Emissions From Dumping Soil Cap Material

Equation 6 was used to estimate VOC emissions from the dumping of soil into the thermal desorption/incinerator system. The temporary storage pile is exposed as the feed system accepts the soil. An exposure time value of 1900 seconds was used in Reference 2 and is also used here. The depth of soil used is 151 cm. Table 21 presents the results.

TABLE 20. EMISSIONS FROM TRANSPORT OF SOIL CAP MATERIAL--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	3.13×10^{-6}	4.10×10^{-4}	0.8664
1-Butanol	1.36×10^{-7}	1.78×10^{-5}	0.0376
Methyl ethyl ketone	3.46×10^{-7}	4.54×10^{-5}	0.0960
Total (Zone 1)	3.61×10^{-6}	4.73×10^{-4}	
Zone 2			
Methylene chloride	5.87×10^{-6}	7.69×10^{-4}	0.5636
Methyl ethyl ketone	2.60×10^{-7}	3.41×10^{-5}	0.0250
o-Xylene	4.28×10^{-6}	5.62×10^{-4}	0.4114
Total (Zone 2)	1.04×10^{-5}	1.37×10^{-3}	

TABLE 21. EMISSIONS FROM DUMPING AND TEMPORARY STORAGE OF SOIL CAP AT THE INCINERATOR FEED SYSTEM--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	4.35×10^{-6}	5.70×10^{-4}	0.8484
1-Butanol	2.19×10^{-7}	2.87×10^{-5}	0.0427
Methyl ethyl ketone	5.58×10^{-7}	7.32×10^{-5}	0.1088
Total (Zone 1)	5.13×10^{-6}	6.72×10^{-4}	
Zone 2			
Methylene chloride	9.06×10^{-6}	1.19×10^{-3}	0.5623
Methyl ethyl ketone	4.20×10^{-7}	5.51×10^{-5}	0.0261
o-Xylene	6.63×10^{-6}	8.70×10^{-4}	0.4116
Total (Zone 2)	1.61×10^{-5}	2.11×10^{-3}	

4.3.6 Emissions from Exposure of Contaminated Soil Layer

The soil characteristics (low moisture, compacted soil) were considered identical to those of the soil cap. The emissions generated from exposure of the contaminated soil were based on the bulk concentrations reported in Table 2. Equation 4 was used to estimate the emissions for each contaminant in each zone; Raoult's Law was used to calculate K_{eq}. Table 22 summarizes the results.

TABLE 22. EMISSIONS FROM THE EXPOSED CONTAMINATED SOIL LAYER--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	1.91×10^{-6}	1.44×10^{-3}	0.3546
1-Butanol	4.70×10^{-7}	3.55×10^{-4}	0.0872
Methyl ethyl ketone	3.01×10^{-6}	2.27×10^{-3}	0.5581
Total (Zone 1)	5.39×10^{-6}	4.06×10^{-3}	
Zone 2			
Methylene chloride	1.31×10^{-5}	9.91×10^{-3}	0.8357
Methyl ethyl ketone	1.94×10^{-6}	1.46×10^{-3}	0.1232
o-Xylene	6.46×10^{-7}	4.87×10^{-4}	0.0411
Total (Zone 2)	1.57×10^{-5}	1.19×10^{-2}	

4.3.7 Emissions From Excavation of the Contaminated Soil Layer

Equation 4 was used to estimate excavation emissions and to account for losses from exposure of the contaminated waste layer because of removal of the soil cap and subsequent layers. An exposure time of 60 seconds and depth of 90 cm was used in the emissions calculations. Table 23 presents the results.

TABLE 23. EMISSIONS FROM EXCAVATION OF THE CONTAMINATED SOIL LAYER--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	3.32×10^{-6}	2.51×10^{-3}	0.3546
1-Butanol	8.18×10^{-7}	6.17×10^{-4}	0.0873
Methyl ethyl ketone	5.23×10^{-6}	3.94×10^{-3}	0.5581
Total (Zone 1)	9.37×10^{-6}	7.07×10^{-3}	
Zone 2			
Methylene chloride	2.28×10^{-5}	1.72×10^{-2}	0.8356
Methyl ethyl ketone	3.37×10^{-6}	2.54×10^{-3}	0.1233
o-Xylene	1.12×10^{-6}	8.47×10^{-4}	0.0411
Total (Zone 2)	2.73×10^{-5}	2.06×10^{-2}	

4.3.8 Emissions From Contaminated Soil Layer in the Excavation Bucket

Equation 6 was used to estimate VOC emissions from the contaminated soil layers in each zone while they were in the excavation bucket. An exposure time of 30 seconds and depth of 150 cm were used in the computations. Table 24 presents the results.

4.3.9 Emissions From Truck Filling With the Contaminated Soil Layer

Equation 6 was used to estimate VOC emissions from truck filling with the contaminated soil layer from each zone. An exposure time of 60 seconds and depth of 51 cm were used in the equation to estimate the emission rates. Table 25 presents the results.

4.3.10 Emissions From Soil Transport of the Contaminated Soil Layer

Equation 6 was used to estimate VOC emissions from the transport of the contaminated soil layer. An exposure time of 720 seconds and depth of 51 cm were used to estimate emission rates for each compound. Table 26 presents the results.

TABLE 24. EMISSIONS FROM CONTAMINATED SOIL LAYER WHILE IN EXCAVATION BUCKET--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	1.41×10^{-6}	1.06×10^{-3}	0.3545
1-Butanol	3.47×10^{-7}	2.62×10^{-4}	0.0874
Methyl ethyl ketone	2.22×10^{-6}	1.67×10^{-3}	0.5581
Total (Zone 1)	3.97×10^{-6}	2.99×10^{-3}	
Zone 2			
Methylene chloride	9.67×10^{-6}	7.29×10^{-3}	0.8353
Methyl ethyl ketone	1.43×10^{-6}	1.08×10^{-3}	0.1234
o-Xylene	4.77×10^{-7}	3.57×10^{-4}	0.0412
Total (Zone 2)	1.16×10^{-5}	8.73×10^{-3}	

TABLE 25. EMISSIONS FROM TRUCK FILLING WITH THE CONTAMINATED SOIL LAYER--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	5.85×10^{-6}	4.41×10^{-3}	0.3545
1-Butanol	1.44×10^{-6}	1.09×10^{-3}	0.0874
Methyl ethyl ketone	9.22×10^{-6}	6.95×10^{-3}	0.5581
Total (Zone 1)	1.65×10^{-5}	1.24×10^{-2}	
Zone 2			
Methylene chloride	4.02×10^{-5}	3.03×10^{-2}	0.8353
Methyl ethyl ketone	5.94×10^{-6}	4.48×10^{-3}	0.1234
o-Xylene	1.98×10^{-6}	1.50×10^{-3}	0.0412
Total (Zone 2)	4.81×10^{-5}	3.63×10^{-2}	

TABLE 26. EMISSIONS FROM TRANSPORT OF THE CONTAMINATED SOIL LAYER--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	2.02×10^{-5}	1.53×10^{-2}	0.3544
1-Butanol	5.00×10^{-6}	3.77×10^{-3}	0.0875
Methyl ethyl ketone	3.19×10^{-5}	2.40×10^{-2}	0.5581
Total (Zone 1)	5.71×10^{-5}	4.30×10^{-2}	
Zone 2			
Methylene chloride	1.39×10^{-4}	1.05×10^{-1}	0.8350
Methyl ethyl ketone	2.05×10^{-5}	1.55×10^{-2}	0.1236
o-Xylene	6.87×10^{-6}	5.18×10^{-3}	0.0413
Total (Zone 2)	1.66×10^{-4}	1.25×10^{-1}	

4.3.11 Emission From Dumping of Contaminated Soil Layer

Equation 6 was used to estimate VOC emissions from truck dumping into the incinerator feed system. An exposure time of 1900 seconds and depth of 51 cm were used in the emission rate estimation. Table 27 presents the results.

TABLE 27. EMISSIONS FROM DUMPING OF CONTAMINATED SOIL LAYERS--SITE B

Compound	Emission rate, g/cm^3	Emission rate, g/s	Fractional VOC percentage
Zone 1			
Benzene	3.26×10^{-5}	2.46×10^{-2}	0.3540
1-Butanol	8.10×10^{-6}	6.11×10^{-3}	0.0879
Methyl ethyl ketone	5.14×10^{-5}	3.88×10^{-2}	0.5580
Total (Zone 1)	9.21×10^{-5}	6.95×10^{-2}	
Zone 2			
Methylene chloride	2.23×10^{-4}	1.68×10^{-1}	0.8350
Methyl ethyl ketone	3.32×10^{-5}	2.51×10^{-2}	0.1236
o-Xylene	1.16×10^{-5}	8.41×10^{-3}	0.0413
Total (Zone 2)	2.74×10^{-4}	2.07×10^{-1}	

4.3.12 Incinerator Emissions

Estimates of VOC emissions from the incinerator stack were based on a 99.99 percent destruction removal efficiency of the concentration remaining in the contaminated soil. This was equivalent to 1.41×10^{-5} g/s for the Zone 1 soils, and 7.86×10^{-4} g/s for Zone 2 soils. Additional computations would be required to estimate the products of combustion but these were not calculated because this study concerns VOCs. The incinerator emissions were modeled as a point source in subsequent steps.

4.3.13 Summary of Emissions Estimates for Site B

A review of the preceding tables for Site B reveals that no substantial variation occurs in the fractional percentage contribution of any given VOC within soil layers (i.e., soil cap or contaminated soil zone) or within homogeneous zones (Zone 1 or 2). This illustrates that once other parameters are set (e.g., remediation steps, time for any given step, the depth of contamination, and the soil characteristics) the relative emission rate is controlled by the concentration and physical/chemical characteristics of the contaminant. Thus, a relatively fixed ratio of chemical constituents is calculated for VOC emissions from either zone. In addition, the contaminated soil layers provide the largest contribution to the overall emission rate. This is illustrated in Table 28.

TABLE 28. SPECIES CONTRIBUTIONS TO OVERALL VOC EMISSIONS--SITE B

Compound	Fraction percent for Type I soil	Fraction percent for Type II soil	Fraction percent for overall excavation
Zone 1			
Benzene	0.8665	0.3544	0.3613
1-Butanol	0.0376	0.0877	0.0870
Methyl ethyl ketone	0.0959	0.5579	0.5516
Zone 2			
Methylene chloride	0.5637	0.8354	0.8310
Methyl ethyl ketone	0.0250	0.1234	0.1217
o-Xylene	0.4113	0.0412	0.0473

The contribution of each remedial step to the VOC emissions was examined. Table 29 presents the results for each step. Although different chemical constituents and concentrations are present in each zone, the contribution of each remedial step to the VOC emissions in the overall excavation process is relatively constant. This contribution appears to be independent of the concentration of chemical species; rather, it depends more on the parameters of the soil and the remedial activity pattern. At this site, dumping and temporary storage at the incinerator feed account for 50 percent of the VOC emissions. Transport from the excavation zone is the second highest contributor of emissions. All activities are assumed to be uncontrolled. The use of tarps and/or foam suppressants could substantially reduce these emissions from transport and storage.

TABLE 29. REMEDIAL STEP CONTRIBUTION TO VOC--SITE B

Remedial activity	Zone 1	Zone 2	Overall site
Excavation	0.0515	0.0507	0.0509
Bucket	0.0220	0.0217	0.0218
Truck filling	0.0912	0.0902	0.0905
Transport	0.3085	0.3039	0.3051
Dumping	0.4979	0.5029	0.5016
Incinerator	0.0001	0.0019	0.0014
Exposed soil	0.0288	0.0286	0.287

Because remediation of the two zones occurs in sequence, the VOC emissions characteristics and the relative contribution of each constituent change depends on which zone is being remediated first. For illustration purposes, Zone 1 is assumed to be remediated first. Figure 5 is an emission profile for total VOC emissions during the total remediation period of 6 months. The emissions from Zone 2 are higher primarily due to higher concentrations of compounds with greater volatility than occur in Zone 1.

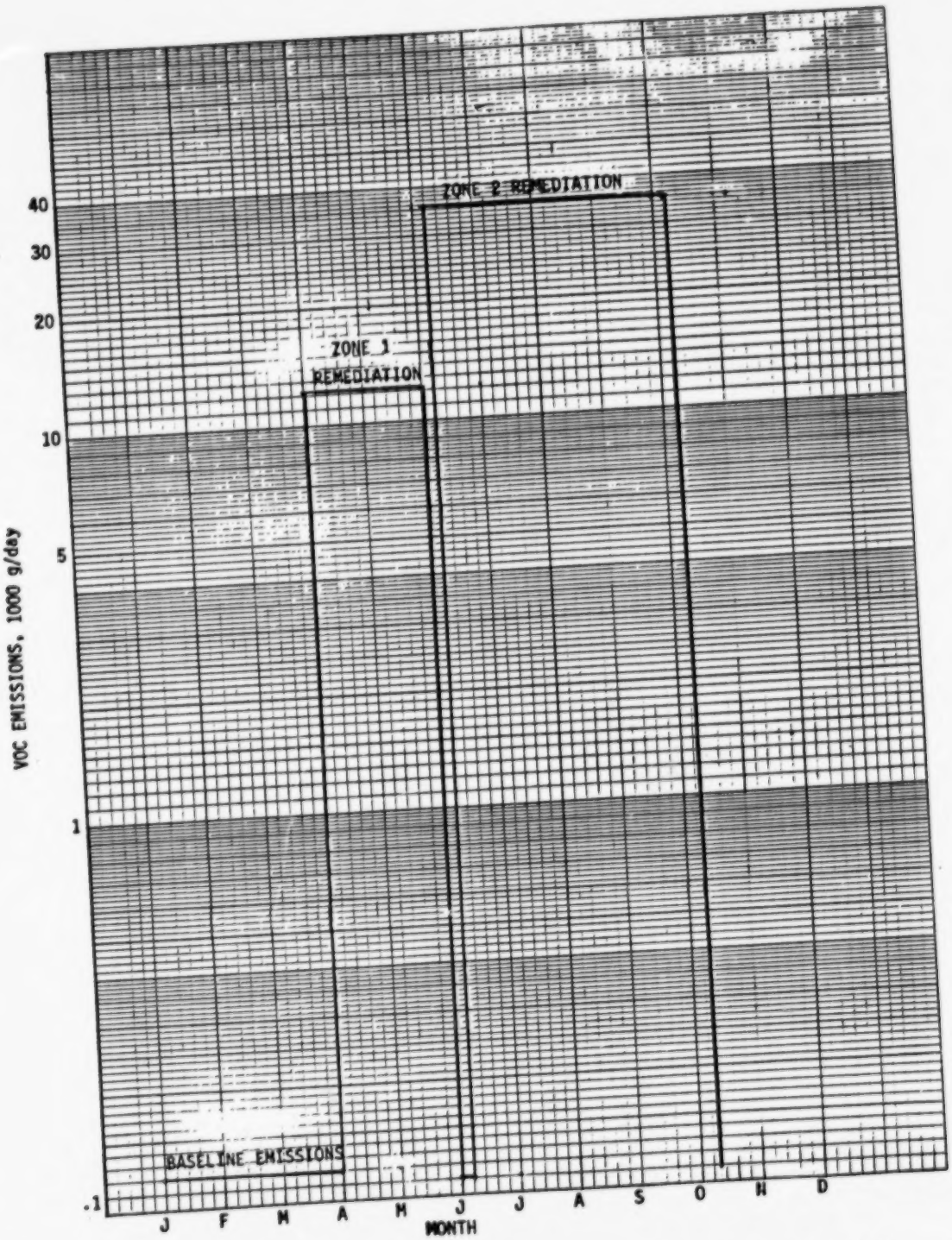

Figure 5. Emissions profile for total VOCs from Zones 1 and 2 remediation--Site B.

4.4 SUMMARY OF EMISSION ESTIMATES

Because the procedures for estimating emissions are intensive, repetitive, and sequential, the use of a computer program is encouraged for performing a detailed analysis. For Site A, approximately 100 calculations were required to provide an estimate of the emissions rate for each step of the excavation process for all five chemicals. For Site B, where two separate homogeneous zones containing three chemicals each were identified, approximately 160 calculations were required. The estimates of fractional contributions required additional calculations. For a large heterogeneous site where subdivision into smaller homogeneous areas would likely be the preferred choice, the calculation requirements could be substantial.

The calculation procedures suggest that, although site-specific factors can be input into the equation for equipment-related factors (e.g., bucket size or remediation cycle time), standardized values for the remediation rates and equipment should be used. Factors correlating with low, medium, and high rates of remediation perhaps could be selected for analysis purposes. For these example sites, mid-range remediation rates should be selected.

The results indicate that the relative emission contributions of each chemical do not change substantially with each remediation step during excavation. This was true within a given soil layer (i.e., the soil cap or the contaminated soil layer). The emissions from the contaminated soil zone accounted for the dominant proporation of the VOC emissions compared with the soil cap. Thus, calculations could be simplified substantially by the elimination of soil cap emissions unless the soil cap contains a substantial quantity of VOCs and represents a substantial percentage of the soil to be remediated. In the example sites, the assumed VOC content of 1 percent of the contaminated soil layer resulted in minor emissions compared with those from the contaminated soil layer.

Results for the Site B example indicate that the VOC emissions for each remediation step occur at a relatively fixed ratio regardless of the VOC characteristics and concentration. This indicates that these ratios are governed by the parameters used to describe the remediation steps (i.e., cycle time, depth of contaminated layer, and remediation rate) and not by the chemical or physical characteristics of the chemical constituents. If this

is true, certain scenarios could be proposed for site remediation and VOC emissions allocated on the basis of remediation steps, initial concentrations in the contaminated soil zone, and rates of remediation (e.g., low, medium, or high).

The emission rates computed through these equations served as the basis of dispersion modeling to determine the ambient impact of remediation. Determining that the relative contributions of each VOC to the overall VOC emission rate remained constant was helpful in describing the emission rate and determining the modeling process, which is the next step in this procedure.

SECTION 5

AMBIENT DISPERSION MODELING

The ambient impact associated with remedial activities and the emissions they generate can be estimated through the use of dispersion models. Three computer-based models were used to estimate short- and/or long-term ambient concentrations associated with remediation of the example sites. The procedures used and the results obtained are summarized in this section.

5.1 GENERAL APPROACH TO DISPERSION MODELING

When the emission rates were defined for each chemical and remediation step, the ambient concentration of each compound could be estimated. The procedure, however, was not as simple as inputting the emission rate into the appropriate dispersion model and waiting for the results. Because the dispersion models used are not specifically designed for some of the remediation activities at Superfund sites, some adaptions and simplifications are required to obtain "reasonable" results. For example, the dispersion models contain algorithms for estimating ambient concentrations associated with point, area, and, depending on the model, volume sources. The models do not, however, address excavation characteristics or dumping and transporting of soil directly and some effort must be expended to adapt these processes to the model input requirements.

The Industrial Source Complex Models (both the ISCLT and ISCST versions) and the SCREEN Model were used for this project. The ISCLT model computes the values necessary for the annual ambient concentrations used for chronic exposure risk assessment, whereas the ISCST computes the predicted values for short-term (acute) exposure. Output results for ISCST can be calculated for several averaging periods, including highest 1-hour, 3-hour, 8-hour, and 24-hour ambient concentrations. The SCREEN Model uses stability class and windspeed data to compute 1-hour ambient concentration at discrete distances. Each model has its strengths and weaknesses as well as its own input and output format. These are discussed briefly in this section.

The ISC Models were considered for use first because they can estimate ambient impacts from multiple source locations and source types simultaneously. The ISC Models can estimate ambient contributions at discrete receptor sites from point sources, area sources, volume sources, and line sources. Each of these source types can be present at a Superfund site. A point source may be present as an incinerator, air stripper, or in situ soil vapor extraction stack. An area source may be present as a contaminated soil layer or pile. Volume sources may be represented by truck filling, and dumping, whereas line sources may be representing emissions from truck transport down a haul road. The contribution of each source or group of sources to the ambient concentration may be displayed in the model output for discrete receptor sites as well as the total contribution of all sources. The ISC Models also use actual historical meteorological data to predict ambient concentrations.

The capability of the ISC Model to model many sources and source types adds a degree of complexity to the overall procedure. The onsite location, dimensions, source type, and emission rate (in the proper format for the model input) must be calculated for each source and input into the model. The receptor locations also must be selected. Specific points oriented to the site or a grid of concentric receptor points located at various distances from the "site center" may be selected. As the number of sources on site increases, the input requirements become more substantial and more computer time is needed to estimate the contribution of each source at each receptor. In addition, increasing the number of receptors to be evaluated increases computer run time. The high level of specificity has a price, particularly for the ISCST Model. It is quite easy to define 20 or more emission sources at a typical Superfund site where excavation is used. This large number of sources presents more opportunity for data input errors. More important for the ISCST Model, however, are the computer run-time requirements. Run times could exceed 20 hours (when an AT class PC running at 6 MHz with a math coprocessor is used). The ISCLT Model does not demand the same run time; typical run time for the ISCLT Model was approximately 10 minutes with the same computer. Clearly, some simplification is justified unless site-specific factors dictate the need for such detail.

The SCREEN Model is very simple to use for short-term estimates. The SCREEN Model is limited to area and point sources, does not consider combined

source impacts at discrete receptors (these have to be manually calculated), does not use site-specific meteorological data, and calculates only 1-hour average concentrations at the receptor of interest. The greatest strengths of the SCREEN model, however, are the ease of inputting data by using screen prompts and the ability to obtain the results in a matter of seconds. Guidelines are available for converting the 1-hour averages to 3-hour, 8-hour, and 24-hour averages. Conversion of a 1-hour value to an annual average is somewhat more complex and was not performed during this project. For the long-term annual concentrations, the ISCLT Model was used.

The fact that the excavation sources are "moving" sources (i.e., the location of the excavation changes daily) is a problem to both models. For these example sites, this would have a greater effect on short-term values than on long-term values. Under certain meteorological conditions, excavation at locations near the fenceline and closest to the receptors may generate high short-term concentrations. Changing location by a distance of 100 meters may reduce short-term concentrations by a factor of two or more, depending on wind and stability conditions.

Two simplifying assumptions were made to help in the modeling. First, the emissions from the actual excavation, the material in the bucket, and truck filling operations were combined and considered as one area source. The emissions associated with exposure of the contaminated soil can be combined with the excavation emissions for the short-term emissions. For long-term emissions the exposed area source was modeled as being immediately adjacent to the excavation source. Truck-hauling emissions and truck-dumping emissions were considered as separate sources. The second simplifying assumption was that the excavation location was on the edge of the contaminated zone (midline) in each case. Calculations of the area exposed daily were based on the area of contamination and the number of estimated days required for remediation. The following equation was used:

$$\text{Exposed area } \frac{m^2}{day} = \frac{\text{Area of contamination } (m^2)}{\text{Days required for excavation}} \qquad (8)$$

Other options are available for estimating the location of the emissions on site, but the preceding assumptions concerning location and quantities of VOC emissions seemed reasonable.

The use of the SCREEN Model required the estimation of maximum 1-hour concentrations by manually summing the impacts from all sources. The computed maximum concentration value from the SCREEN Model was based on worst-case meteorological data from an array of atmospheric stability classes and windspeeds contained within the SCREEN Model. The fact that the relative contribution of each chemical constituent remained constant throughout the remedial process within a homogeneous zone simplified the model runs considerably. If variable contributions were found, a modeling run for each chemical would be required to determine the ambient concentration of each VOC.

One substantial difference exists between the long-term and short-term modeling. The emission rates for the long-term model reflect the annual average emission rate. The emissions generated during 2 months of excavation at Site A and 6 months of excavation at Site B were converted to an annual average emission rate. This can be performed by calculating the total emissions generated during the remediation for each step and dividing by the number of seconds in a year (31,536,000 s/yr). The ISCLT Model was run with the VOC emissions "annualized" to produce an annual ambient concentration. The SCREEN Model, on the other hand, was run with actual maximum hourly emission rates to determine the short-term ambient concentrations associated with the remediation steps at each site. All remediations taking less than 1 year would require similar adjustment. The results from the ISCLT model are used in the risk assessment step, whereas the SCREEN Model results can be used for contingency monitoring and for defining short-term "action level" detection limits or identifying the potential for acute toxicity problems.

5.2 DISPERSION MODELING FOR SITE A

The locations of the sources and emission rates were determined for Site A and input into the ISCLT Model and the SCREEN Model. The combined emissions from excavation, material in the bucket, and truck filling were all classified as one area source for the ISCLT Model. The size of this source was estimated as a square with a side of 5.9 m (34.84 m^2). The emissions from the exposed contaminated waste layer due to soil removal were included in the ISCLT model as a separate but adjacent source of identical size. The

total annualized VOC emission rate for excavation was estimated at 3.25 x 10^{-4} g/s per m^2, and the exposed area source VOC emissions were estimated at 2.43 x 10^{-4} g/s per m^2. The locations for these two area sources were established (grid coordinates: 0,0) at the center of site. Estimated ambient contributions of VOCs from the trucks that used the haul road were estimated by representing the VOC emissions from the trucks as series of 10 volume sources along the 100-meter haul road. The annualized VOC emission rate for the length of the haul road was 3.00 x 10^{-2} g/s or 3.00 x 10^{-3} g/s from each of the 10 segments. A release height of 3 meters was selected. These data and the coordinates for the receptor locations were input into the ISCLT Model. The meteorological data selected for the example represented the Raleigh, North Carolina, area. The output was selected to show the relative contribution of each source group at each receptor. Receptors at the fenceline of the site were also selected. Figure 6 shows the relative position of sources and receptors.

The ISCLT program estimated the annual ambient concentration for all receptors in increments of 22.5-degree sectors around the site at the fenceline and at distances ranging from 250 to 20,000 meters from the site center. As expected from these types of sources, maximum ambient impact occurred at the fenceline because the close proximity and low level release heights provide little time for dispersion. The highest annual concentration (7.23 $\mu g/m^3$) was found due north (0 degrees) of the site center at the fenceline (100.6 meters). Table 30 presents the fenceline VOC values. In general, the highest annual concentrations are predicted for the north and east of the site. The relative contribution of each source to the ambient concentration receptors is not constant, primarily because of the wind data, emission rates, ISC algorithms, and relative location of each source within the site.

Short-term ambient concentrations may be determined with the SCREEN Model. For this site, the worst condition would logically occur when winds were lined up with all the sources (north-south orientation). The combined effects from excavation, exposed soil, and truck-hauling emissions would be the greatest with these wind conditions.

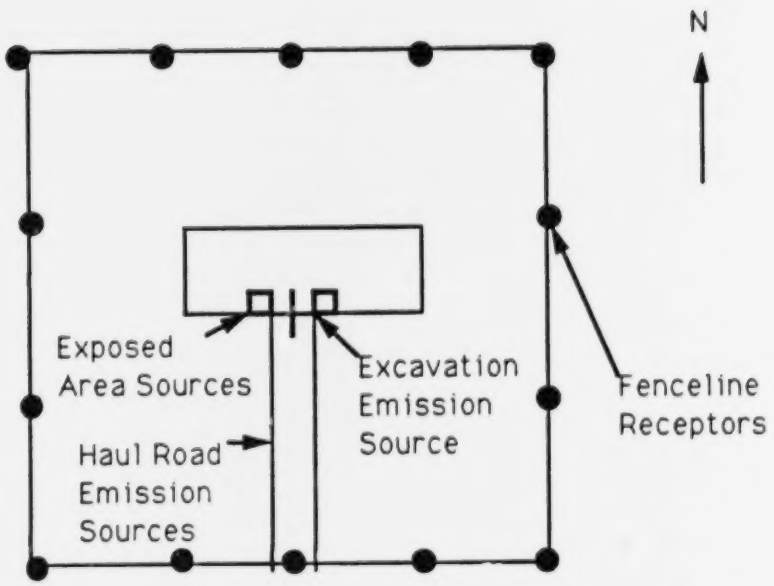

Figure 6. Relative location of emission sources and fenceline receptor for Site A.

TABLE 30. FENCELINE VOC CONCENTRATIONS FROM ISCLT MODEL RUN FOR SITE A

Azimuth, degrees	Range, meters	Annual average ambient concentration, $\mu g/m^3$
0	100.6	7.23
22.5	112.5	7.20
45.0	142.3	5.16
67.5	112.5	6.84
90.0	100.6	5.48
112.5	112.5	3.80
135.0	142.3	2.55
157.5	112.5	3.98
180.0	100.6	5.11
202.5	112.5	3.40
225.0	142.3	2.13
247.5	112.5	2.24
270.0	100.6	3.23
292.5	112.5	2.88
315.0	142.3	2.01
337.5	112.5	3.03

The short-term ambient concentrations of concern would result from short-term emissions from the various excavation processes. The model input requires the short-term emission rate during actual excavation hours. The exposed area source and excavation emissions could be simplified by adding them together and treating them as one area source. The truck-hauling emissions would be handled separately as 10 separate elevated area sources. The results would then be combined manually.

The short-term VOC emission rates were estimated by taking the VOC emission rate (g/cm^3) and multiplying it by the quantity of soil actually moved during the 8-hour remediation period each day. Because the 24-hour average rate was 885 cm^3 soil/s, the average hourly rate during remediation must be increased by a factor of three (24/8) or 2665 cm^3/s during the 8-hour shift. Therefore, the short-term VOC emissions are 2.04×10^{-1} g/s from excavation and 5.07×10^{-2} g/s from the exposed soil. Short-term emissions from soil transport were estimated to be 5.41×10^{-1} g/s. The SCREEN Model does not handle volume sources, but the ambient effects from the truck emissions could be modeled as a series of 10 small elevated area sources at

discrete distances from the site boundary and adding their effects together at the receptor of interest. This works well for a wind from the south because all distances from the source to the receptor would exceed the accepted minimum of 100 meters for modeling results. Winds form the north would place receptors very close to the emission "points" from the truck hauling, and results would be questionable. Thus, only winds from the south were considered.

The SCREEN Model predicted the highest 1-hour concentration under F class stability (moderately stable atmospheric conditions) and a windspeed of 1.0 m/s from the SCREEN Model's array of stability class and windspeed data. Under these conditions, the ambient impact from the combined excavation sources at the fenceline was predicted to be 4621 μg VOC/m^3. The truck-hauling emissions were modeled as 10 elevated area sources (each a square source with a side dimension of 3 meters) with an area of 9 m^2 each. Each of these sources was located 10 meters apart along down the haul road, starting at 5 meters from the site center (105 meters from the northern fenceline). The total contribution of all the truck hauling sources was estimated to be another 5577 $\mu g/m^3$, for a total of 10,198 $\mu g/m^3$ for the highest 1-hour value.

The fractional percentage of each compound in the ambient air at a given receptor is identical to the fractional emission rate for each compound emitted from a source. The contribution of multiple sources to the concentration at a given receptor would have to be weighted. This is particularly true when different fractional contributions of VOCs are involved from multiple sources. Because these fraction emission rate relationships stay relatively constant for all excavation remedial steps within a homogeneous zone, ambient concentrations can be determined by multiplying the ambient concentrations by the average fractional percentage emission of each VOC. Table 31 presents the values for each of the five compounds by applying the factors presented in Table 16. The concentrations estimated for methylene chloride represent the most prevalent compound expected followed by methyl ethyl ketone and benzene. These values are used in the risk assessment for this site (Section 6) for both long- and short-term exposure.

TABLE 31. AMBIENT CONCENTRATIONS FOR CHEMICAL SPECIES AT SPECIFIED RECEPTORS

Azimuth, degrees	Range, meters	Benzene, $\mu g/m^3$	1-Butanol, $\mu g/m^3$	Methylene chloride, $\mu g/m^3$	Methyl ethyl ketone, $\mu g/m^3$	o-Xylene, $\mu g/m^3$
			Annual concentrations			
0	100.6	0.36	0.04	5.92	0.62	0.29
22.5	112.5	0.36	0.04	5.90	0.62	0.29
45.0	142.3	0.26	0.03	4.23	0.44	0.21
67.5	112.5	0.34	0.04	5.60	0.59	0.28
90.0	100.6	0.27	0.03	4.49	0.47	0.22
112.5	112.5	0.19	0.02	3.11	0.33	0.15
135.0	142.3	0.13	0.01	2.09	0.22	0.10
157.5	112.5	0.20	0.02	3.26	0.34	0.16
180.0	100.6	0.25	0.03	4.19	0.44	0.21
202.5	112.5	0.17	0.02	2.78	0.29	0.14
225.0	142.3	0.11	0.01	1.74	0.18	0.09
247.5	112.5	0.11	0.01	1.83	0.19	0.09
270.0	100.6	0.16	0.02	2.65	0.28	0.13
292.5	112.5	0.14	0.01	2.36	0.25	0.12
315.0	142.3	0.10	0.01	1.65	0.17	0.08
337.5	112.5	0.15	0.02	2.48	0.26	0.12
			Maximum 1-hour concentration			
0	100.6	504.8	53.0	8353.2	874.0	412.0

5.3 DISPERSION MODELING FOR SITE B

The mathematical approach used for Site B was similar to that used for Site A except that the two distinct contaminated zones were modeled separately. Also Site B includes more sources because an onsite thermal desorber/incinerator is used in the soil remediation (Figure 7).

The emissions from excavation, material in the bucket, and truck filling were all combined into one area source for input into the ISCLT Model. The exposed contaminated soil layer was considered a second adjacent area source for the ISCLT Model. The emissions from the onsite truck transport were modeled as a segmented series of elevated volume sources. Dumping into the incinerator feed system was also considered a volume source. The incinerator stack was modeled as a point source. The ISCLT Model was run twice--once for each zone--because the emissions profile of chemical constituents for the two

zones differs. A single model run could have been made, but it would have required the model output to display the contribution of each source to each receptor and the chemical constituent makeup of each source. By assuming two separate remediation zones and the remediation of each performed sequentially rather than simultaneously, the ambient concentration of each compound at each receptor could be determined by simple multiplication of the fractional contribution of each compound. Only for methyl ethyl ketone (present in both zones) would the annual ambient concentration results have to be added together.

The ISCLT modeling results for Site B included results from 12 defined sources in Zone 1 and 16 defined sources in Zone 2. As expected, the maximum ambient concentrations for remediation of each zone occurred at the fenceline of the site due to low release heights of neutral buoyancy plumes. Meteorological data representing Raleigh, North Carolina, were used in the model runs. Emission rates for each source were converted to annual average emission rates.

For Zone 1, the annualized VOC emission rates for excavation activities, material in the bucket, and truck filling were estimated to be 1.10×10^{-4} g/s per m^2. The annual emissions from the exposed contaminants were estimated to be 1.920×10^{-5} g/s per m^2. Each area source was estimated to cover 34.86 m^2, and they were located adjacent to each other at the midline point and edge of the Zone 1 contamination for modeling purposes. The emissions from truck hauling were divided into eight volume source segments, each emitting at an annual average of 8.94×10^{-4} g/s. Truck dumping into the incinerator was also treated as a volume source with an annual average emission rate of 1.15×10^{-2} g/s. The incinerator stack was treated as a point source with an annual average emission rate of 1.41×10^{-5} g/s. The coordinates (location) for each of these sources were also input into the model.

For Zone 2, similar source data were calculated except that truck hauling was divided into 12 volume segments rather than 8 as in Zone 1 because of a longer haul road. Also, the location of the sources (except for the incinerator feed system and the incinerator system) is different in Zone 2. The input emission rates for the combined excavation sources were 6.39×10^{-4} g/s per m^2 and 1.12×10^{-4} g/s per m^2 for the exposed contaminated waste layer. The emission rate for transport was 3.47×10^{-3} g/s for each segment

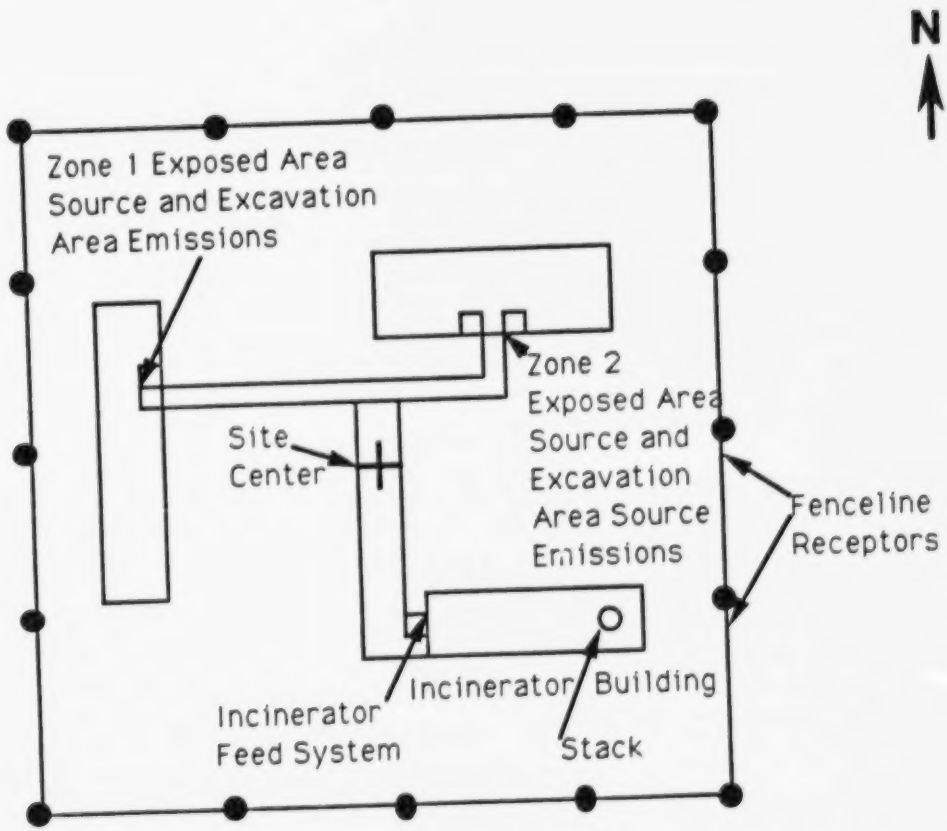

Figure 7. Site B source configuration and receptor locations.

and 6.70×10^{-2} g/s for dumping emissions. The incinerator emission rate was 7.86×10^{-4} g/s.

The modeling results for each run indicated that the highest concentrations would occur at the fenceline for the remediation of either Zone 1 or Zone 2. The ambient concentration at each differ because of differences in emission rates and the relative position of the various sources. Table 32 presents the annual concentrations for each zone. All receptor positions are relative to the site center.

The annual VOC concentrations at each receptor could be added together, but it is more advantageous to determine the fractional contribution of each chemical from each zone and then to add the appropriate VOCs. Only one compound, methyl ethyl ketone, fits this additive category. Table 33 presents the annual concentrations of each compound. These values are based on the fractional emission contribution from each zone (Table 28).

The emissions from Zone 2 produce higher ambient VOC concentrations at the designated receptors than do the emissions from Zone 1 for two reasons. First, emission rates from Zone 2 are higher than those from Zone 1. Second, the length of time required to remediate Zone 2 is 4 months. This longer period of emissions results in a higher annual ambient impact.

Short-term modeling with SCREEN is more complicated for this site because of site orientation. Information presented in the site orientation map for emission sources suggests that the highest emission potential differs for remediation of the two zones. For Zone 1 the highest potential would appear to occur when winds were aligned in a northwest-southeast direction. During remediation of Zone 2, the highest potential would appear to occur from a N-S or NNE-SSW wind orientation. This is one situation where the ISCST Model would be helpful because of the complex site orientation. The run-time penalties associated with the ISCST Model (20 to 24 h per run), however, are substantial, and the speed associated with the SCREEN model make it a better choice for estimating short-term ambient concentrations.

The actual predicted emission rates during the daily remediation activities were used as input for the short-term SCREEN Model. The results of the model runs for the individual source groups indicate that emissions during dumping at the incinerator feed system have the highest potential for ambient impacts, followed by losses during truck hauling and emissions during excavation activities. This is consistent with the results of the emission

TABLE 32. ANNUAL AMBIENT VOC CONCENTRATIONS AT FENCELINE FOR SITE B

Azimuth, degrees	Range, meters	Zone 1 concentration, $\mu g/m^3$	Zone 2 concentration, $\mu g/m^3$
0	122.5	2.65	12.47
22.5	137.4	1.92	17.33
45.0	173.2	1.10	9.28
67.5	137.4	1.20	11.26
90.0	122.5	1.08	8.49
112.5	137.4	0.76	5.56
135.0	173.2	0.59	3.78
157.5	137.4	0.99	6.97
180.0	122.5	1.80	10.22
202.5	137.4	1.38	6.71
225.0	173.2	0.85	4.14
247.5	137.4	1.09	4.37
270.0	122.5	1.38	5.66
292.5	137.4	1.29	5.18
315.0	173.2	0.83	3.95
337.5	137.4	1.44	5.56

TABLE 33. AMBIENT CONCENTRATION OF EACH CHEMICAL AT FENCELINE RECEPTORS--SITE B

Azimuth, degrees	Range, meters	Benzene, $\mu g/m^3$	1-Butanol, $\mu g/m^3$	Methylene chloride, $\mu g/m^3$	Methyl ethyl ketone, $\mu g/m^3$	o-Xylene, $\mu g/m^3$
0	122.5	0.96	0.23	10.36	2.98	0.59
22.5	137.4	0.69	0.17	14.40	3.17	0.82
45.0	173.2	0.40	0.10	7.71	1.74	0.44
67.5	137.4	0.43	0.10	9.36	2.03	0.53
90.0	122.5	0.39	0.09	7.06	1.63	0.40
112.5	137.4	0.27	0.07	4.62	1.10	0.26
135.0	173.2	0.21	0.05	3.14	0.79	0.18
157.5	137.4	0.36	0.09	5.79	1.39	0.33
180.0	122.5	0.65	0.16	8.49	2.24	0.48
202.5	137.4	0.50	0.12	5.58	1.58	0.32
225.0	173.2	0.31	0.07	3.66	1.01	0.21
247.5	11375	0.39	0.09	3.63	1.13	0.21
270.0	122.5	0.50	0.12	4.70	1.45	0.27
292.5	137.4	0.47	0.11	4.30	1.34	0.25
315.0	173.2	0.30	0.07	3.28	0.94	0.19
337.5	137.4	0.52	0.13	4.62	1.47	0.26

rate calculations. Although the visual assessment of the site plot would suggest that the greatest alignment comes with a wind from the northwest when Zone 1 is remediated, the high emission rate and the proximity of the incinerator dump and feed system to the southern property line suggest the highest 1-hour concentration would occur under F-stability class when the winds are from the north. An ambient concentration (1-h average) of 3633 $\mu g/m^3$ was predicted by the SCREEN Model.

A similar situation occurs with the remediation of Zone 2. Alignment of sources is greater with the winds from the NNW direction. The SCREEN Model, however, predicts that the highest impact occurs when winds are from the west because of the dumping area's proximity to the fenceline. The highest predicted 1-hour ambient concentration was 10,676 $\mu g/m^3$ during F-stability conditions.

The SCREEN Model will not calculate the effect of multiple sources, and a manual method had to be developed. When the SCREEN Model is run, the user selects an array of discrete distances to estimate ambient concentrations at various distances from the source. Through a visual procedure (a ruler helps), different combinations of sources are estimated for different wind directions. As the wind "crosses" each emission source, the distance to the appropriate fenceline point is estimated and the ambient contribution from that source to that receptor is determined. The ambient contribution from each source is added to determine the total ambient concentration at the receptor of interest. This procedure is similar to the ISC Model's receptor estimation technique.

The sequential remediation of Zones 1 and 2 means that distinct 1-hour maximum concentrations can be associated for each chemical during remediation as a fraction of the total VOC release rate from each zone. Table 34 presents the peak 1-hour concentrations.

TABLE 34. PEAK 1-HOUR CONCENTRATIONS FOR EACH COMPOUND

Compound	Maximum 1-hour concentration, $\mu g/m^3$	Zone
Benzene	1312	1
1-Butanol	316	1
Methylene chloride	8871	2
Methyl ethyl ketone	2004.7	1
o-Xylene	495	2

5.4 SUMMARY OF DISPERSION MODELING RESULTS

The dispersion model results for each site require several simplifying assumptions. First, the emission rates at the excavation area were grouped together into a single emission rate to reduce the complexity of the modeling. Second, the position of the excavation was placed at one point within the contaminated area. The midpoint of the long side of the contaminated zone at the edge nearest the haul road was selected. Other options are available and can be explored further. The model limitations, however, prevent accurate modeling of the moving excavation source or changing truck-hauling patterns in either version of the ISC Models. Finally, each homogeneous area was modeled separately because it appeared easier to determine the ambient effects separately and then to combine them where appropriate.

As of now, the run-time penalties associated with the ISCST Model appear to be too great to include the use of this model in a remediation site evaluation. If use of the SCREEN Model indicates there may be problems with short-term ambient concentrations, use of the ISCST Model may then be warranted to provide a more detailed evaluation. The SCREEN Model produces results quickly although they have to be added manually to determine the effects at a receptor of interest. The ISCLT and SCREEN Model results also indicate that where the receptor with the maximum ambient concentration will

occur is not explicitly obvious because of differences in source strengths and site geometry; however, most interested parties should be able to make a good estimate.

Although these predicted ambient concentrations are often perceived and used as absolute values, they really should be viewed as probabilities. The ISC Models use historical meteorology data, and the predicted ambient concentrations depend not only on the algorithms used but also on meteorological characteristics. The implied assumption is that the historical meteorology is representative of the actual or expected future meteorology. The SCREEN Model is a little more specific in predicting ambient concentrations if certain stability class and windspeeds are present. It does not, however, use wind direction patterns to predict where, the specific ambient concentrations will occur relative to the site orientation. These limitations were considered in the use of these predicted ambient concentrations in the site risk assessment.

SECTION 6

RISK ASSESSMENT

The procedures outlined in this section are used to predict the risk associated with exposure to the various VOCs. This risk assessment, which depends on predicted ambient concentrations and risk values assigned for each chemical, represents the last step in the process of evaluating the effects of remediation.

6.1 GENERAL APPROACH TO RISK ASSESSMENT

Several elements must be considered in the risk assessment of a remedial activity. These include acute and chronic exposure effects from exposure to each chemical released during remediation and the carcinogenic and noncarcinogenic effects. Although there is much debate as to the appropriateness of such estimation procedures, guidance does exist for the evaluation of chronic exposures to both carcinogens and noncarcinogens and work is currently underway within the EPA to provide guidance in the evaluation of acute (short-term) exposures.

The risk assessment procedures differ for carcinogens and noncarcinogens. Data for evaluating risks were found in the Health Effects Assessment Summary Tables (HEAST) manual for carcinogens and noncarcinogens. Of the chemicals in this analysis only benzene and methylene chloride are listed as carcinogens in the HEAST manual. Methyl ethyl ketone and o-xylene are listed as noncarcinogenic toxicants, and 1-butanol is not currently listed. Methylene chloride is also listed for having other noncarcinogenic toxic effects. Risk assessments were conducted only for the compounds for which data were available.

The noncarcinogenic toxicity effects are expressed as a function of reference doses (RfDs). For the compounds noted, the chronic RfDs are reported as mg/m^3 for continuous, 24 h/day exposure over any given 1-year period. A hazard index for each compound can be determined by the following equation:

$$HI_i = \frac{(\text{Annual concentration})_i}{RfD_i} \quad (9)$$

where HI_i = Hazard index of compound i

RfD_i = Reference dose for compound i

$(\text{Annual concentration})_i$ = Annual average ambient concentration of i at the location of interest.

If more than one compound is involved, the hazard indices for each should be calculated and then summed. In general, concerns about noncarcinogenic toxicity effects would be expected only if

$$\Sigma HI_i \geq 1.0$$

For the purposes of noncarcinogenic toxic effects, the ambient concentration found from the ISCLT annual average may be compared directly with the RfD values. When compounds have both noncarcinogenic and carcinogenic effects, the RfD refers only to the noncarcinogenic endpoint. A hazard index of less than 1.0 for any compound or groups of compounds may not be protective for carcinogenic effects. The RfDs for the compounds used in this study are 1) methylene chloride = $3x10^{0}$ mg/m^3, 2) methyl ethyl ketone = $3x10^{-1}$ mg/m^3, and 3) o-xylene = $7x10^{-1}$ mg/m^3. Standard body weight and breathing rates are assumed in the derivation of these values.

The carcinogenic potency factors listed in the HEAST manual are based on chronic exposure extended over a 70-year lifetime. The unit cancer risk values reported in the HEAST manual may be converted to a specific increased lifetime cancer risk as follows for each carcinogen by the following equation:

$$\text{Increased Lifetime Cancer Risk} = \text{Ambient concentration } (\mu g/m^3) \times \text{Unit Cancer Risk } (\mu g/m^3)^{-1} \quad (10)$$

A limitation exists for remedial activities. The increased lifetime risk values are based on 70 years of continuous exposure, whereas most remediation activities will be completed in much less time. In the case of the remediation scenarios presented, herein, the time required to complete excavation is less than 1 year. The annual average ambient concentrations determined by the ISCLT Model were based on conversion of the short-term

emission rates to an annual average (as if the emission occurred over the entire year at a reduced rate rather than in the 2- or 4-month time period actually estimated). After remediation is completed, however, the ambient concentration from remediation falls to zero. Thus, the annual ambient concentration value for the cancer risk assessment must be adjusted by the number of years required for remediation.

$$\text{Adjusted ambient concentration} = \text{Annual ambient concentration} \times \text{No. of years for remediation}/70 \quad (11)$$

The number of years for remediation will always be greater than or equal to 1 because the annual ambient concentration for remediation periods of less than 1 year already reflect adjustment to an annual average emission rate. The annual ambient concentrations estimated by the ISCLT Model for the example sites must be divided by a factor of 70 because the remediation time is less than 1 year. This methodology assumes cancer risk is the same whether the dose is received over a short time period at high levels or over a lifetime at very low levels. Although the correctness of the approach is debatable, it is nevertheless the current policy of the Superfund program.

The National Contingency Plan (NCP) calls for the increased acceptable cancer risk (aggregated for each chemical for each pathway) to be less than 1×10^{-4} (less than 1 in 10,000). The NCP also states that this acceptable risk should be achieved for the maximum exposed individual (MEI). The MEI has not been defined for this project. Fenceline values were used for risk comparison because they represent the highest annual concentrations.

6.2 RISK ASSESSMENT FOR SITE A

A quick comparison of the maximum ambient concentrations of methylene chloride, methyl ethyl ketone, and o-xylene indicates that the noncarcinogenic hazard index for each chemical and the chemicals in total is very small; therefore, the chronic noncarcinogenic risks associated with these compounds during remediation are small.

The carcinogenic risks associates with the remediation scenario are also very small, well below the 10^{-4} threshold defined in the NCP. The highest concentration values were taken from the fenceline receptors (Table 31 in Section 5) and converted to cancer risk values as follows:

$$\text{Benzene cancer risk} = (0.36/70)(8.3 \times 10^{-6}) = 4.3 \times 10^{-8} \quad (12)$$

$$\text{Methylene chloride cancer risk} = (5.92/70)(4.7 \times 10^{-7}) = 4.0 \times 10^{-8} \quad (13)$$

The aggregate cancer risk for these two compounds is 8.3×10^{-8}, which is well below the acceptable increased cancer risk range.

Less guidance is available on how to evaluate the short-term acute exposure that may occur. One method would be to compare the short-term ambient concentration potential (8-hour average) with the Threshold Limit Value (TLV) recommended by American Conference of Governmental and Industrial Hygenists (AGCIH) or with the Permissible Exposure Limit (PEL) as regulated by the Occupational Safety and Health Administration (OSHA). Site monitoring contingency plans frequently reference these values with some safety margin, but the selection of these values is relatively arbitrary at this time. None of the short-term ambient concentrations approaches the TLV or PEL values.

6.3 RISK ASSESSMENT FOR SITE B

As in the case of Site A, the annual concentrations of the compounds with noncarcinogenic toxic effects from Site B are very small when compared with the RfD values; thus, the total hazard index would be considerably less than 1.0. Chronic noncarcinogenic risks associated with the remediation of this site are small.

The carcinogen risks associated with Site B are somewhat larger than those for Site A, but well within the acceptable range defined by the NCP. The highest concentration values were taken from fenceline receptors and converted to increased cancer risk values as follows:

$$\text{Benzene cancer risk} = (0.96/70)(8.3 \times 10^{-6}) = 1.1 \times 10^{-7} \quad (14)$$

$$\text{Methylene chloride cancer risk} = (14.40/70)(4.7 \times 10^{-7}) = 9.7 \times 10^{-8} \quad (15)$$

The aggregate increased cancer risk for the two compounds is 2.1×10^{-7}, which is below the acceptable increased cancer risk range.

The short-term ambient concentrations are below the TLV and PEL values in all cases except for methyl ethyl ketone. The ACGIH recommends a not-to-be-exceeded ceiling value of 1500 $\mu g/m^3$. The SCREEN Model results

predicted that a value of 2005 $\mu g/m^3$ could be expected under certain meteorological conditions at the fenceline. The OSHA PEL for methyl ethyl ketone for an 8-hour time-weighted average is 590 mg/m^3. Again guidance is not currently available to indicate whether this remediation approach would present a problem.

6.4 SUMMARY OF RISK ASSESSMENT RESULTS

The results of the risk assessments for carcinogenic and noncarcinogenic effects of the remediation and site scenarios indicate that the risks from chronic exposure are within an acceptable range. This conclusion is based on several assumptions, including site characterization, emission rate estimates, ambient dispersion modeling, and the risk assessment procedures themselves. Different assumptions or site characteristics might change the conclusion. The risk assessment procedure is the least complicated because straightforward guidance is provided for converting ambient concentrations to risk.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

Analysis of remedial alternatives for a Superfund site depends on several steps, including site characterization, emission rate calculations, dispersion modeling analysis, and risk assessment. Each step in the process clearly involves its own uncertainty factors, but the overall uncertainty factor for the entire process is not clear.

It is assumed that Superfund site characteristics will be given, including soil characteristics, extent and nature of the contamination, and the location of the contaminated zones. It may be necessary to subdivide the site into smaller homogeneous zones of contamination for remediation analysis purposes.

The steps to be followed during remediation must be defined for the analysis of ambient impacts. This requires some knowledge of the remedial alternatives to be considered and a definition of the major subtasks within the remedial alternative. Evaluating emissions generation on the basis of exact equipment use or precise rates of remediation, may not be possible, but typical equipment ranges could be selected for ranges of remediation rates.

Manually calculating the emission rates to estimate the individual VOC rates from each step in the excavation is a time-consuming task. The several basic formulas used to calculate emissions from each excavation step are repetitive and sequential and each step requires a change of only three variables. Emission rate calculations were performed for each of the five chemicals identified in this project. These calculation procedures led to two useful conclusions. First, the relative contribution after each evacuation step to total VOC emissions is virtually constant throughout the excavation effort. For example, if methylene chloride constitutes 88 percent of the VOC emissions from the first step (excavation of the contaminated soil zone), it will also constitute nearly 88 percent from the last step (dumping to a storage pile). The equations predict that some slight decrease in pollutant concentration of highly volatile compounds should occur because of

losses at each step, however, the emission ratios between VOCs remain essentially constant. The emission rate of any given compound depends on the chemical's physical properties and on its initial concentration.

The second conclusion reached was that the release rate of each VOCs from each remediation step in a homogeneous zone is constant with respect to the overall VOC emission rate and is independent of the VOC concentration in the soil. The equations depend more on the definition of the remediation step characteristics than on the concentrations themselves. Thus, it may be possible to determine the relative contribution of each VOC to the overall VOC emission rate and to apply simple factors for the contribution of each remediation step. For example, the excavation of the soil cap and the contaminated soil zone produced 11.54 percent of the total estimated VOC emissions for Site A (Table 15). Although the emission rate of each of the five compounds varied (in g/cm^3 soil handled or g/s), the percent contribution for each individual compound to its total emission rate did not vary. The emissions of each compound (benzene, methylene chloride, methyl ethyl ketone, 1-butanol, and o-xylene) from the excavation step represented 11.54 percent of the total emissions for each compound (i.e., 11.54 percent of all benzene emissions for the site came from excavation; 11.54 percent of all methylene chloride emissions from the site came from excavation, etc.). If the ratios between emissions of various compounds are established from their concentration in the soil (Table 14: 81.91 percent methylene chloride, 8.57 percent methyl ethyl ketone, 4.95 percent benzene, etc.) and the relative contribution of each step in the remediation process is defined, then simplified factors can be developed. The excavation step is the first step of the process and setting all emission rates relative to it produces a series of multiplication factors for each compound in subsequent steps. These are presented in Table 35. Thus, if the estimated emission rate for methylene chloride was 3.0×10^{-2} g/s from excavation, then the predicted emission from the other step would be this value multiplied by the appropriate factor. It should be noted that these factors would vary depending on the remediation steps included (i.e., these factors differ when onsite storage and incineration are included). But if well-defined scenarios could be developed, then the appropriate multipliers could be developed. Different ranges of remediation rates could be selected to represent typical values.

TABLE 35. REMEDIATION EMISSION FACTOR MULTIPLIERS FOR SITE A

Remedial activity	Factor
Excavation	1.00
Bucket	0.39
Truck filling	0.58
Transport	5.23
Exposure of contaminated zone	1.47

The dispersion models themselves present some problems. Of necessity, the position of a source cannot change between days, nor can a variable emission rate be selected. These realities of Superfund remediation are not adequately addressed by currently available dispersion models. These limitations are probably more important for short-term modeling than for long-term modeling. The SCREEN Model and the ISCLT Model were the ambient dispersion models used to produce short-term and long-term results, respectively. The ISCST Model was also considered, but computer run times were too long for the scenarios modeled so it was dropped from consideration. The strength of the ISC models is their ability to estimate impacts from multiple sources at specific receptors of interest under site meteorological conditions. Satisfactory run times are achieved for the ISCLT Model, and short-term emissions were converted to annual averages for ISCLT.

The principal advantages of the SCREEN Model are that it is fast and easy to use. For simple sites with one or two emission points, the SCREEN Model should produce satisfactory results. As the sites become more complex and contain more sources, the inability of the SCREEN Model to account for multiple sources necessitates performing more manual calculations and graphical determinations of orientation and impacts of specific sources on specific receptors. In some situations, site orientation may be very complex, and determination of the short-term ambient impacts may be difficult. If complex sites are encountered, the use of ISCST may be warranted with only a few receptors of interest (to shorten the computer run time) to determine if potential problems exist with a proposed remediation scenario.

The risk assessment for each site involved both carcinogenic and noncarcinogenic compounds. Values for reference doses for chronic exposure to the noncarcinogens may be compared directly with the ambient concentrations predicted by the ISCLT model. The hazard indices for the noncarcinogens at both sites were well below the levels of concern for chronic exposures. The values for carcinogens had to be adjusted for comparison of predicted ambient concentrations with the unit cancer risk values. The published unit cancer risk values are based on chronic 70-year exposures, and remediation of the sites took considerably less time. This adjustment increased the "allowable" concentration for a specific risk value by a factor of 70 for both sites. With these adjustments, the computed increased cancer risks were well below the 10^{-4} threshold specified in the NCP.

The approach used for this set of evaluations is not the only methodology available. Judgment may be exercised in subdividing a site, other computation methods may be used to estimate emission rates, and different methods may be used for setting up dispersion models or for selecting dispersion models.

The manual computations for the excavation of the two sites produced detailed emission rate estimates for each chemical and each excavation step. For a single chemical in a homogeneous zone, a minimum of 20 computational steps are required to estimate emission rates for each excavation step. Although the equations used are identical (requiring only changes in the physical values that define the step) and sequential (requiring the accounting of VOCs lost from all previous steps) the potential for calculation errors becomes greater as the complexity of the site increases. The addition of more chemicals or more homogeneous areas increases the number of calculations substantially. Compared with other requirements for site evaluation, the emission rate calculations took a substantial amount of time.

Two other approaches may be used to estimate emissions. The first involves establishing a graphical procedure with simplified "look-up" tables. Standardized remediation rates based simply on low, medium, and high rates could be established with standardized equipment specifications. Because emission rates are a function of chemical and physical characteristics and chemical concentration, it may be possible to assign numerical values to these more common compounds based on the vapor pressure, molecular weight,

and diffusion coefficients of the compounds. Calculation procedures could be provided for compounds not included in the listing, adjustment factors could be provided for different soil types, and the emission rates could be provided for the initial excavation step. All other emissions from hauling and dumping would be multiplied factors of the initial excavation emissions.

A graphical procedure to evaluate ambient impacts from remediation could be provided on the basis of exposed area and distance to receptors. From the graphical determination of dispersion coefficients and emission rates, an estimated ambient concentration for the compound(s) of concern could be determined. This would then be compared with the unit cancer risk values to estimate the risk associated with the excavation remedial option.

The second approach would involve computerizing the calculation procedures. The emission rate equations certainly lend themselves to this procedure because the equations require replacement of variables related to the chemical and to the process step involved. A data base for chemicals with appropriate physical values that are automatically selected could be incorporated into the program. Factors such as soil characteristics could be defined with default values or could allow for user changes.

Ideally, the computerized approach should allow the user to answer a few questions about the site characteristics, site orientation, and concentrations in the soil; calculations for emission rates, ambient concentrations, and site risk assessments could then be automatically performed. This may be possible but the recommended approach would be to develop a modularized calculation system. One module would be a data base for chemicals, another would be a module for calculating emission rates from various remediation techniques, and a third could include health effects data. Modules could be updated as new data become available. The major limitation would appear to be the assembling of information into the proper formats so that the ambient dispersion models would run properly in a complete package.

The graphical approach might be used as a conservative, quick, manual screening method for estimating impacts from remediation of a simple site. A more complex site or one that indicates potential problems might call for more refined modeling or for the more intensive and faster calculating ability that can be incorporated into a computer program. Very large and/or complex sites appear to require the abilities of a computer to estimate

emission rates and the combined ambient effects from remediation because the effects from multiple sources are not always intuitive. Some simple method of evaluating a remedial alternative is necessary to evaluate risk, as required by the NCP.

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